DRIFT OF FISHES IN THE SAN JUAN RIVER 1991-1997

Final Report

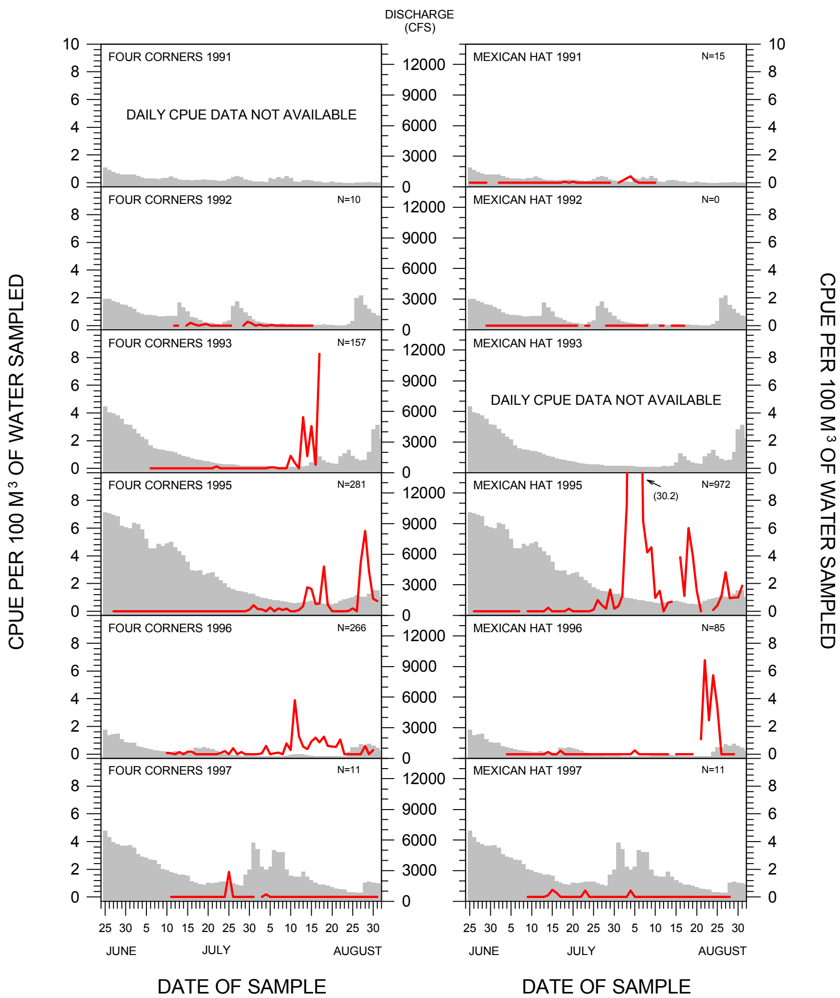

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF TABLES

EXECUTIVE SUMMARY

This study of the drifting fishes in the San Juan River from 1991-1997 was one component of the extensive biological research activities conducted under the San Juan River Recovery Implementation Program. The primary objectives of the passive drift-netting study were to 1) determine the temporal distribution of San Juan River ichthyoplankton in relation to the hydrograph, 2) provide comparative analysis of the reproductive success of San Juan River fishes, 3) attempt to characterize downstream movement of ichthyoplankton, and 4) attempt to validate the presumed spawning period of Colorado pikeminnow (*Ptychocheilus lucius*).

A total of 13,683 drifting larval fish, representing eight taxa, were collected over the tenure of the seven year study. Overall larval fish catch rates were about equal at the upper (Four Corners, New Mexico) and lower (Mexican Hat, Utah) collecting localities. However, nonnative channel catfish (*Ictalurus punctatus*) numerically dominated the catch at the lower site while native speckled dace (*Rhinichthys osculus*), flannelmouth sucker (*Catostomus latipinnis*), and bluehead sucker (*Catostomus discobolus*) were most abundant at the upper site.

The highest number of larval fish, at both sites, was collected in 1995. The most abundant fishes at the lower site during 1995 were nonnative red shiner (*Cyprinella lutrensis*) and channel catfish while speckled dace, flannelmouth sucker, and bluehead sucker were the most abundant taxa at the upper site. Red shiner mean annual catch rates were very high at the upper site in 1991 (low flow year), moderate at both sites in 1995 and 1996, and low during other years sampled. Fathead minnow (*Pimephales promelas*) followed nearly the same annual abundance pattern as red shiner but was far less prevalent than the latter taxon. The highest mean annual catch rates of speckled dace were in 1993, 1994, 1995, and 1997 (high flow years) and lowest speckled dace mean annual catch rate occurred in 1996 (lowest flow year). Native suckers were also nearly absent during 1996 and generally paralleled abundance trends observed for speckled dace. Channel catfish abundance peaked at Four Corners in 1996 and was moderate to high at Mexican Hat for all years of the study.

The correlation between the number of drifting larvae and occurrence of summer rainstorms was relatively consistent throughout the study period for all species analyzed. Rainstorms resulted in low water visibility and high levels of instream debris, conditions during which the majority of drifting larval fish (of all species) were collected. While temporal drift patterns were highly variable, most of the largest collections occurred in late July and early August when both water temperature and the incidence of rain events generally peaked. Increased water velocities, due to rainstorms, may have displaced larval fish from preferred habitats resulting in their passive downstream drift. Alternatively, drifting fish may have actively dispersed under conditions of high turbidity which favored reduced predation.

Drifting Colorado pikeminnow were rare throughout the study period at both sites. Back-calculations, based on larval Colorado pikeminnow capture dates, indicated that the majority of spawning occurred as flow decreased in mid to late July following spring runoff. Mean water temperature during the back-calculated spawning dates of drifting larval pikeminnow (8 July to 18 July) ranged between 18.0°C and 18.5°C and had risen about 5°C several weeks before spawning.

Collection of Colorado pikeminnow from the upper site in 1996 provided additional support for the hypothesized Mixer (RM 131.0-132.0) spawning area. Conversely, two Mexican Hat larval pikeminnow collected in 1995 appear to have originated from the same spawning bar and provide circumstantial evidence of a spawning location markedly downstream of the Mixer Reach. Downstream displacement of Colorado pikeminnow both below instream barriers and into unsuitable habitats and reaches, such as Lake Powell, appear to be a major factor for this species rarity. The hydrologic and behavioral components that contribute to the dispersal of Colorado pikeminnow need to be better understood and addressed before recovery efforts can be expected to achieve sustainable success.

INTRODUCTION

Colorado pikeminnow (*Ptychocheilus lucius*) is a federally endangered species (U.S. Department of the Interior, 1974) endemic to the Colorado River Basin where it was once abundant and widespread (Tyus, 1991). This species now occupies only about 20% of its historic range (Tyus, 1990). The Green River sub-basin apparently support the majority of remaining Upper Basin individuals (Holden and Wick, 1982; Bestgen, 1998). Conversely, no Colorado pikeminnow have been reported in the Lower Basin since the 1960s (Minckley and Deacon, 1968; Minckley, 1973; Moyle, 1976).

A small but self-sustaining population of this species occurs in the lower-most 225 river km (between Cudei Diversion Dam and the inlet of Lake Powell Reservoir) of the San Juan River. The decline of this and other native fishes in the San Juan River has been attributed to flow modifications and the resultant changes to the thermal regime, instream barriers, and non-native predation-competition for habitat and resources. Understanding the conditions necessary for spawning in Colorado pikeminnow and other native fishes was deemed necessary to stabilize and increase the population size of this species.

Much has been reported regarding the life-history and reproductive behavior of Colorado pikeminnow (Vanicek and Kramer, 1969). Studies in the Upper Colorado River Basin (Yampa and Green rivers) have demonstrated that this species spawns as spring runoff is receding and at water temperatures between 18^{o}C and 20^{o}C (Haynes et al., 1984; Nesler et al., 1988). Larval Colorado pikeminnow employ drift as a dispersal mechanism and are presumed to begin this passive movement approximately five days after hatching. The five-day time-frame corresponded with the swim-up period of this fish as reported by Hamman (1981, 1986).

This life-history phase (drifting larvae), the focus of several investigations in the Upper Colorado River Basin, has been investigated to provide information on spawning bar location, reproductive success, and the effects of various flow-regimes on reproduction. The collection of a juvenile (177 mm TL) Colorado pikeminnow in 1978 (Minckley and Carothers, 1979) and rediscovery of a reproducing population of Colorado pikeminnow in the San Juan River in 1987 (Meyer and Moretti, 1988; Platania and Bestgen, 1988; Platania et al., 1991) demonstrated a need for studies to ascertain information such as that obtained for this species in the Upper Colorado River Basin. Such studies would also provide comparable information on other members of the ichthyofaunal community.

In 1991, passive drift-netting for larval and young-of-year (YOY) fish was initiated in the San Juan River. The primary objectives of the passive drift-netting study were to 1) determine the temporal distribution of San Juan River ichthyoplankton in relation to the hydrograph, 2) provide comparative analysis of the reproductive success of San Juan River fishes, 3) attempt to characterize downstream movement of ichthyoplankton, and 4) attempt to validate the presumed spawning period of Colorado pikeminnow. Acquisition of these data would be integrated with hydrologic and other biological studies to develop management options for the San Juan River. Biological data could then be compared with San Juan River hydrology patterns to develop models that correlate Colorado pikeminnow reproductive success and annual discharge patterns. These objectives met goals 5.3.2 (Determine the status and trends of resident fish species), 5.3.3 (Determine the life history of endangered and other native fish species and relationships to all other resident fish species), and 5.3.5 (Characterize fish community response to different annual flow regimes) as defined in the San Juan River Recovery Implementation Program (SJRIP) document.

STUDY AREA

The San Juan River is a major tributary of the Colorado River and drains 99,200 km^2 in Colorado, New Mexico, Utah, and Arizona (Figure 1). From its origins in the San Juan Mountains of southwestern Colorado at elevations exceeding 4,250 m, the river flows westward for about 570 km before confluencing with the Colorado River. The major perennial tributaries to the San Juan River are (from upstream to downstream) Navajo, Piedra, Los Pinos, Animas, La Plata, and Mancos rivers, and McElmo Creek. In addition there are numerous ephemeral arroyos and washes that contribute relatively little flow annually but input large sediment loads.

Navajo Reservoir, completed in 1963, impounds and isolates the upper 124 km of the San Juan River and regulates downstream discharge. The completion of Glen Canyon Dam in 1966 and subsequent filling of Lake Powell ultimately inundated the lower 87 km of the San Juan River by the early 1980s. The San Juan River is now a 359 km lotic system bounded by two reservoirs (Navajo Reservoir near its head and Lake Powell at its mouth).

The San Juan River is canyon-bound and restricted to a single channel between its confluence with Chinle Creek (ca. 20 km downstream of Bluff, Utah) and Lake Powell. The river is predominately multi-channeled upstream of Chinle Creek with the highest density of secondary channels occurring between Bluff and the Hogback Diversion (ca. 13 km upstream of Shiprock, New Mexico). There is a general downstream decline in channel stability in the section of river between Bluff and Shiprock. Below the confluence with the Animas River near Farmington, New Mexico, the channel is less stable and more subject to floods from it largest and unregulated tributary, the Animas River. Conversely, the regulated reach of river between Farmington, New Mexico and Navajo Dam is relatively stable with few secondary channels.

From Lake Powell to Navajo Dam, the mean gradient of the San Juan River is 1.67 m/km. Examined in 30 km increments, river gradient ranges from 1.24 to 2.41 m/km but locally (i.e., <30 km reaches) can be as high as 3.5 m/km. Between Shiprock and Bluff, San Juan River substrate is primarily sand mixed among some cobble. The proportion of sand is greatest in the downstream most reaches and declines along an upstream gradient. From Farmington to Navajo Dam, the San Juan River substrate is dominated by embedded cobble. Although less embedded, cobble is also the most common substrate between Shiprock and Farmington.

Except in canyon-bound reaches, the river is bordered by nonnative salt cedar (*Tamarix chinensis*) and Russian olive (*Elaeagnus angustifolia*) and native cottonwood (*Populus fremontii*) and willow (*Salix* sp.). Nonnative woody plants dominated nearly all sites and resulted in heavily stabilized banks. Cottonwood and willow accounted for less than 15% of the riparian vegetation.

The characteristic annual hydrographic pattern in the San Juan River is typical of rivers in the American Southwest with large flows during spring snowmelt, followed by low summer, autumn, and winter base flows. Summer and early autumn base flows are frequently punctuated by convective storm-induced flow spikes. Prior to closure of Navajo Dam, about 73% of the total annual San Juan River drainage discharge (based on USGS Gauge # 09379500; Bluff, Utah) occurred during spring runoff (1 March through 31 July). Median daily peak discharge during spring runoff was 10,400 cfs (range = 3,810 to 33,800 cfs). Although flows resulting from summer and autumn storms contributed a comparatively small volume to total annual discharge, the magnitude of storm-induced flows exceeded the peak snowmelt discharge about 30% of the years, occasionally exceeding 40,000 cfs (mean daily discharge). Both the magnitude and frequency of these storm induced flow spikes are greater than those recorded in the Green or Colorado rivers.

Closure of Navajo Dam altered the annual discharge pattern of the San Juan River. The natural flow of the Animas River ameliorated some aspects of regulated discharge by augmenting spring discharge. Regulation resulted in reduced magnitude and increased duration of spring runoff in wet years and substantially reduced magnitude and duration of spring flow during dry years.

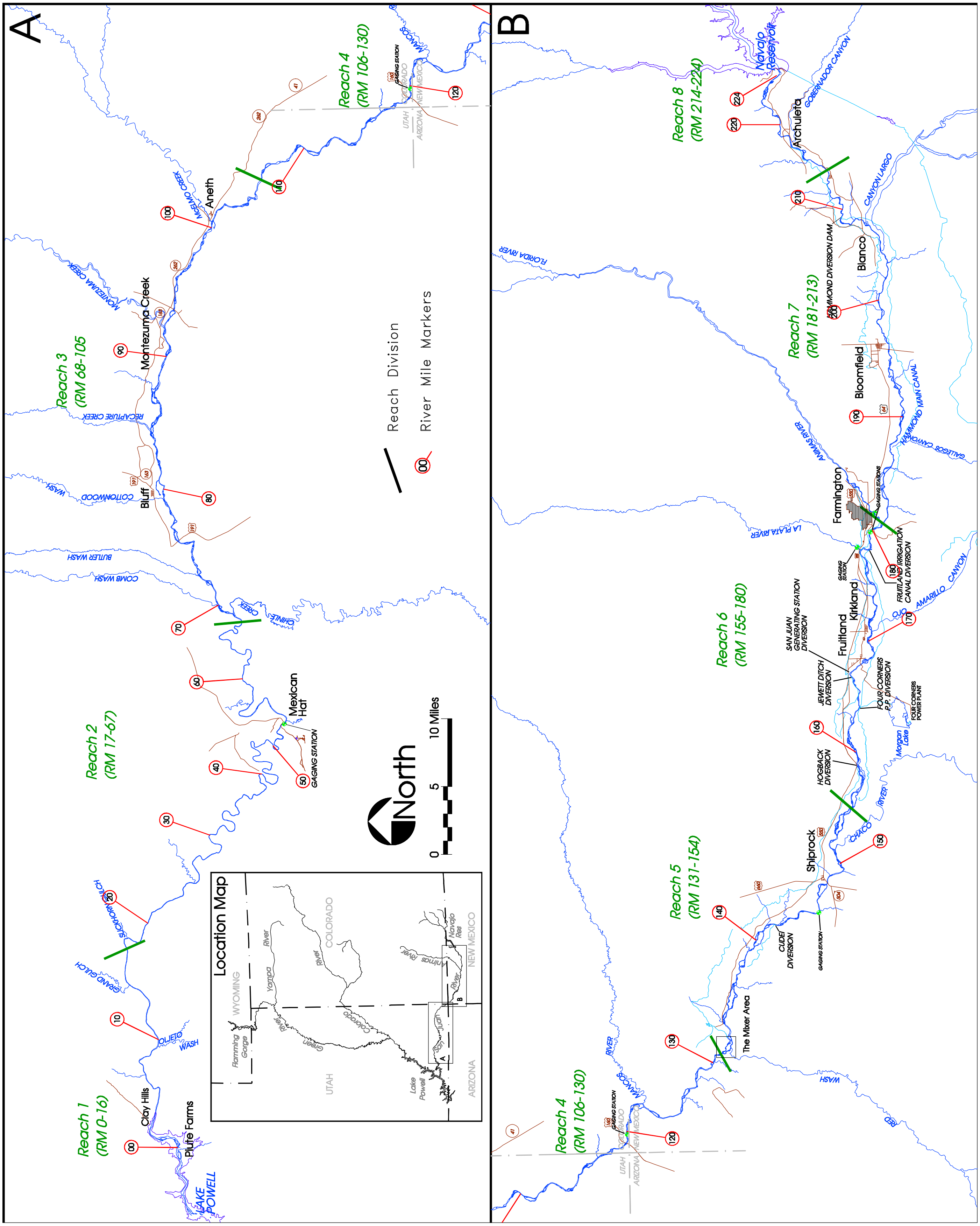

Figure 1. Study area in the San Juan River

Overall, flow regulation by operation of Navajo Dam has resulted in post-dam peak spring discharge averaging about 54% of pre-dam values. Conversely, post-dam base flow increased markedly over pre-dam base flows.

Since 1992, Navajo Dam has been operated to mimic a “natural” San Juan River hydrograph with the volume of release during spring linked to the amount of precipitation recorded during the preceding winter. Thus in years with high spring snowmelt, reservoir releases were “large” and “small” in low runoff years. Base flows since 1992 were typically greater than during pre-dam years but less than those between 1964-1991.

The primary study area for most investigations conducted under the auspices of the San Juan River Seven Year Research Program, including that reported herein, were accomplished in the mainstem San Juan River and its immediate vicinity between Navajo Dam and Lake Powell. There is considerable human activity within the floodplain of the San Juan River between Shiprock and Navajo Dam. Irrigated agriculture is practiced throughout this portion of the San Juan River Valley and adjacent uplands. Much of the river valley not devoted to agriculture (crop production and grazing) consists of small communities (e.g., Blanco and Kirtland) and several larger towns (e.g., Bloomfield and Farmington). The Animas River Valley is similarly developed. Small portions of the river valley and uplands from Shiprock to Bluff are farmed with dispersed livestock grazing as the primary land use. In the vicinity of Montezuma Creek and Aneth, petroleum extraction occurs in the floodplain and adjacent uplands. There are few human-caused modifications of the system from Bluff to Lake Powell.

A multivariate analysis of a suite of geomorphic features of the San Juan drainage was performed to segregate the river into distinct geomorphic reaches, enhance comparison between studies, and to provide a common reference for all research. This effort (Bliesner and Lamarra, 1999) resulted in the identification of eight reaches of the San Juan River between Lake Powell and Navajo Dam. A brief characterization of each reach (from downstream to upstream) follows.

Reach 1 (RM 0 to 16, Lake Powell confluence to near Slickhorn Canyon) has been greatly influenced by fluctuating reservoir levels of Lake Powell and its backwater effect. Fine sediment (sand and silt) has been deposited to a depth of about 12 m in the lowest end of this reach since the reservoir first filled in 1980. This deposition of suspended sediment into the delta-like environment of the river/reservoir transition makes it the lowest-gradient reach in the river. This portion of the river is canyon bound with an active sand bottom. Although an abundance of low-velocity habitat is present at certain flows, it is highly ephemeral, being influenced by both river flow and Lake Powell’s elevation.

Reach 2 (RM 17 to 67, near Slickhorn Canyon to confluence with Chinle Creek) is also canyon bound but is upstream of the influence of Lake Powell. The gradient in this reach is greater than in either adjacent reach and the fourth highest in the system. The channel is primarily bedrock confined and influenced by debris fans at ephemeral tributary mouths. Riffle-type habitat dominates, and the only major rapids in the San Juan River occur in this reach. Backwater abundance is low in this reach, usually occurring in association with debris fans

Reach 3 (RM 68 to 105, Chinle Creek to Aneth, Utah) is characterized by higher sinuosity and lower gradient (second lowest) than the other reaches, a broad floodplain, multiple channels, high island count, and high percentage of sand substrate. While this reach has the second greatest density of backwater habitats after peak spring runoff, it is extremely vulnerable to change during summer and autumn storm events. After these storm events, this reach may have the second lowest density of backwaters of the eight reaches. The active channel distributes debris piles throughout the reach following spring runoff, leading to the nickname “Debris Field”.

Reach 4 (RM 107 to 130, Aneth, Utah, to below "the Mixer") is a transitional zone between the upper cobble substrate-dominated reaches and the lower sand substrate-dominated reaches. Sinuosity is moderate compared with other reaches, as is gradient. Island area is higher than in Reach 3 but lower than in Reach 5, and the valley is narrower than in either adjacent reach. Backwater habitats are low overall in this reach (third lowest among reaches) and there is little clean cobble.

Reach 5 (RM 131 to 154, the Mixer to just below Hogback Diversion) is predominantly multi-channeled with the largest total wetted area and greatest secondary channel area of any of the reaches. Secondary channels in this section tend to be longer and more stable (but fewer) than in Reach 3. Riparian vegetation is more dense in this reach than in lower reaches but less dense than in upper reaches. Cobble and gravel are more common in channel banks than sand, and clean cobble areas are more abundant than in lower reaches. This is the lowermost reach containing a diversion dam (Cudei). Backwaters and spawning bars in this reach are much less subject to perturbation during summer and fall storm events than are the lower reaches.

Reach 6 (RM 155 to 180, below Hogback Diversion to confluence with the Animas River) is predominately a single channel, with 50% fewer secondary channels than Reaches 3, 4, or 5. Cobble and gravel are the dominant substrata with cobble bars containing clean interstitial spaces being most abundant in this reach. There are four diversion dams that may impede fish passage in this reach. Backwater habitat abundance is low in this reach, with only Reach 2 containing fewer of these habitats. The channel has been altered by dike construction in several areas to control lateral channel movement and over-bank flow.

Reach 7 (RM 181 to 213, Animas River confluence to between Blanco and Archuleta, New Mexico) is similar to Reach 6 in terms of channel morphology. The river channel is very stable, consisting primarily of embedded cobble substrate as a result of controlled releases from Navajo Dam. In addition, much of the river bank has been stabilized and/or diked to control lateral movement of the channel and over-bank flow. Water temperature is influenced by the hypolimnetic release from Navajo Dam and is colder during the summer and warmer in the winter than that of the river below the Animas confluence.

Reach 8 (RM 213 to 224, between Blanco and Archuleta and Navajo Dam) is the most directly influenced by Navajo Dam, which is situated at its uppermost end (RM 224). This reach is primarily a single channel, with only four to eight secondary channels, depending on the flow. Cobble is the dominant substrate type, and because lateral channel movement is less confined in this reach, some loose, clean cobble sources are available from channel banks. In the upper end of the reach, just below Navajo Dam, the channel has been heavily modified by excavation of material used in dam construction. In addition, the upper 10 km of this reach above Gobernador Canyon are essentially sediment free, resulting in the clearest water of any reach. Because of Navajo Dam, this area experiences much colder summer and warmer winter water temperatures. These cool, clear water conditions have allowed development of an intensively managed blue-ribbon trout fishery to the exclusion of native species in the uppermost portion of the reach.

Two primary sites were selected as drift-netting stations: one was in Reach 4 near the Four Corners area in New Mexico (RM 123-128) and the other was near Reach 2 at Mexican Hat, Utah (RM 53). The Four Corners site was near the upper end of Reach 4 about 4.6 miles upstream of the mouth of the Mancos River. The location sampled was in a relatively habitat-rich one-mile segment of the river bounded at both its upper and lower ends by an extremely braided river channel and complex series of islands. Immediately after flowing through the upstream series of islands and associated secondary channels, the San Juan River formed a single channel. About 0.75 miles downstream of that point, the river channel abutted a canyon wall, followed a sharp (ca. 85°) curve, and traveled about 0.25 miles before reaching the next set of islands and secondary channels. In this one mile reach between islands, the river was confined to a single channel about 30-60 m wide with moderate gradient and cobble dominated substrate. The Four Corners drift-net sampling site was about 0.20 miles downstream of the river's bend in the segment confined to a single channel. The closest and largest point source of inflow and sediment to this drift-net station was Chaco Wash which was located about 4 miles upstream of the study site. The Four Corners site was selected, in part, to provide a sampling location in close proximity to a putative Colorado pikeminnow spawning bar. The original Four Corners site, RM 123, was sampled 1991-1993, while the current site (RM 128) has been sampled from 1992 to present (1999). Except where otherwise indicated, the two Four Corners sites were combined (1992-1993) for all analyses.

The Mexican Hat site was bounded by at least 16 river miles upstream and 53 river miles downstream of canyon confined reaches. This drift-net sampling site was located about 0.5 miles downstream from the downstream end of a 180° river bend and in one of the few open segments of river downstream of Sand Island. Aquatic habitat at this site was characterized by high gradient main channel runs and riffles over a substrate of primarily bedrock. The channel was about 50-75 m wide and generally over 2 m deep. Point sources of water and sediment in closest proximity to this site included Chinle Creek, and Comb, Butler, and Montezuma washes. This site also received the cumulative sediment and drift from sources upstream of the aforementioned tributaries. The Mexican Hat site was sampled every year during the study period and the study site did not changed. This site was chosen because it was the most downstream sampling location that could be easily accessed and readily sampled.

METHODS

Data Collection

Conical plankton nets with an 0.5 m diameter mouth were fitted on rectangular frames (30.5 x 43.5 cm during 1991-1994; 36 x 47 cm during 1995-1997), equipped with removable collection buckets, and used to collect drifting larval fishes (=drift-nets). Nets were 4 m long, had a 560 µm mesh (bar measure) and an open-mesh to net-mouth ratio of 8:1. Tranter and Smith (1968) reported that filtration efficiency approached 100% when open-mesh area was more than three times the area of the net mouth. Rings (6-cm diameter) welded to the corners of the drift-net frame allowed the nets to be attached to steel fence-posts (T-posts) placed in the river. Between one and three nets were used during each set. Nets were placed about 5-10 cm below the water's surface. For most years, the volume of water filtered by each net was measured by mechanical flow-meters suspended in the center of the nets. However, there were years when flow meters were not used with every net at every site and there were also years when flow meters were never deployed. Values of mean daily discharge for the San Juan River were obtained from the United States Geological Survey gauging stations at Four Corners, New Mexico and Bluff, Utah.

Passive drift-netting on the San Juan River at Mexican Hat was conducted by the Utah Division of Wildlife Resources (UDWR) during 1991-1994, samples at Four Corners were taken by New Mexico Department of Game and Fish (NMGF) during 1991-1994, and both sites were sampled by personnel at the Museum of Southwestern Biology, Division of Fishes at the University of New Mexico (UNM) during 1995-1997.

Passive drift-net sampling was conducted daily from late June or early July through mid to late August at all sites for all years (Table 1). This sampling period was selected because it encompassed the reported reproductive season of Colorado pikeminnow (Haynes et al., 1984; Nesler

Table 1. Summary of collection information for the San Juan River drift-net study. For times sampled: M = morning; E = evening. For flow measurements: Y = yes (all sets); N = no (no sets); P = partial (some sets).

(A) Mexican Hat site (RM 53).

Year	Dates sampled	Times sampled	Was flow measured?	Entire sampling period	
				Time (h)	Vol. (100 m^3)
1991	6/25 - 8/9	M	Y	196	528
1992	6/29 - 8/16	M	Y	187	535
1993	6/29 - 8/15	M	N	269	606†
1994	6/20 - 8/16	M	N	257	484†
1995	6/26 - 8/30	M, E	Y	272	429
1996	7/4 - 8/28	M	Y	217	217
1997	7/9 - 8/27	M, E	Y	161	238

(B) Four Corners site (RM 123-128).

Year	Dates sampled	Times sampled	Was flow measured?	Entire sampling period	
				Time (h)	Vol. (100 m^3)
1991	6/24 - 8/9	M	N	108	155†
1992*	7/1 - 8/14	M, E	P	147	323
1993*	7/3 - 8/14	M, E	P	579	1,517†
1994	6/27 - 8/19	M	N	222	410†
1995	6/27 - 8/30	M, E	Y	337	674
1996	7/10 - 8/29	M	Y	197	527
1997	7/11 - 8/30	M, E	Y	207	289

* Represents two locations, upstream (RM 128) and downstream (RM 123). In 1992, flow was measured for some sets at both locations. In 1993, flow was measured in the upstream but not the downstream location. In 1992, time and volume of water sampled do not include 1 July-10 July, when neither time nor flow sampled was recorded. Catch totals in Table 4 do include this time period, but analyses do not.

† Estimated value (see Methods).

et al., 1988; Tyus and Haines, 1991; Bestgen et al., 1998). Severe weather conditions (heavy rainstorms and lightning) occasionally precluded the ability to obtain daily samples. Drift-nets were set for two hours intervals at dawn and occasionally at dusk. Drift-nets often remained in the river for periods greater than two hours during periods of very low flow and low suspended sediment, while the opposite was true when there were large volumes of suspended debris in the river.

At the end of each set, the contents of each drift-net were rinsed, labeled, and preserved in 10% formalin. Drift material was allowed to cure for at least two days before samples were sorted and fishes separated from the debris. Cleaned samples were returned to the laboratory at the Museum of Southwestern Biology (MSB) for identification and curation. All fish specimens were identified to species (where possible) and counted.

Specimens were assigned to categories of “drift” or “incidental” based primarily on their developmental stage. “Drift” referred to individuals with minimal or no control over their longitudinal movement, while “incidental” referred to individuals whose developmental stage indicated that they were not actually a component of the drift but were incidentally captured. Their capture may have been due to strong currents (rainstorm events) or other factors. The primary criterion for identifying a fish as an incidental capture was the presence of fully differentiated fins. The approximate maximum standard length (SL) was determined for each of the San Juan River species with drifting larvae (Table 2).

The principal purpose in making the distinction between drift and incidental captures was because this study was designed to assess drifting larval fish. Fish that accidentally found their way into the drift-net or that were transported downstream due to high flow events provided little information to the overall objectives of the passive drift-netting study. Fish classified as incidental were noted in totals but not included in subsequent analyses.

The term young-of-year (YOY) can include both larval and juvenile fish. It refers to any fish, regardless of developmental stage, between hatching or parturition and the date (1 January) that they reach age 1 (i.e., YOY = Age 0 fish). Larval fish is a specific developmental (morphogenetic) period between the time of hatching and when larval fish transform to juvenile fish. We have chosen to follow larval fish terminology as defined by Snyder (1981). There are three distinct sequential larval developmental stages: protolarvae, mesolarvae, and metalarvae. Fish in any of these developmental stages are referred to as larvae or larval fish. Juvenile fish are those that have progressed beyond the metalarval stage and no longer retain traits characteristic of larval fishes. Juveniles were classified as individuals that 1) had completely absorbed their fin folds, 2) had developed the full adult complement of rays and spines, and 3) had developed segmentation in at least a few of the rays. In this work, YOY-juvenile fish refer to Age-0 non-larval fish.

Morphogenesis nomenclature (larval and juvenile) should not be confused with terms related to downstream passive movement (=drift). For these investigations, the word “drift” is defined as the passive movement of fish in a downstream direction. While drifting fish may have some ability to control their vertical movement, they have not achieved sufficient development to allow them to actively move out of the current and into low-velocity habitats. Fish that have progressed far enough through morphogenesis to be able to control both their vertical and horizontal movement are usually in one of the latter larval stages and are no longer considered drift (non-drift = incidental). All fish classified as drift are larvae, but not all larval fish are drift.

Calculation of Catch-Per-Unit-Effort (CPUE)

Calculation of catch rate required an appropriate measure of effort which, for drift-netting, was volume of water sampled. Catch-per-unit-effort (CPUE) was calculated as number of drifting fish caught per unit volume of water sampled. This measure was deemed the most appropriate estimate for density of larval fish and assessment of reproductive success for each population of fish studied. Volume of water sampled was measured using a mechanical flow-meter attached to each net

Table 2. List of fish species captured in drift-nets 1991-1997, abbreviation used in this report, status (N = native; I = introduced; E = endangered), and approximate maximum size for drifting larvae. Larger or more developed fish were considered incidental captures and not included in analyses. A dash (-) represents those species whose larvae generally do not drift.

Species	Abbrev.	Status	Max. drift length (mm)
red shiner (*Cyprinella lutrensis*)	CYPLUT	I	12
common carp (*Cyprinus carpio*)	CYPCAR	I	12
roundtail chub (*Gila robusta*)	GILROB	N	14
Colorado pikeminnow (*Ptychocheilus lucius*)	PTYLUC	N, E	14
fathead minnow (*Pimephales promelas*)	PIMPRO	I	12
speckled dace (*Rhinichthys osculus*)	RHIOSC	N	12
flannelmouth sucker (*Catostomus latipinnis*)	CATLAT	N	20
bluehead sucker (*Catostomus discobolus*)	CATDIS	N	15
black bullhead (*Ameiurus melas*)	AMEMEL	I	-
channel catfish (*Ictalurus punctatus*)	ICTPUN	I	25
western mosquitofish (*Gambusia affinis*)	GAMAFF	I	-
largemouth bass (*Micropterus salmoides*)	MICSAL	I	-

(as previously described). However, flow was not measured consistently throughout the seven year sampling period and there were also occasional problems with individual flow-meter readings. The meters would sometimes appear to be operating "sluggishly" presumably because sand or silt had infiltrated the internal mechanism and hindered the movement of gears. Procedures for detecting faulty or inaccurate flow-meter readings and for estimating flow were devised to remedy these individual situations.

For each year and site where flow was measured, flow-meter data were examined for missing or unusually low meter readings. Low readings were confirmed as defective if the original field sheets and notes contained corroborative information such as the collectors' observations on flow-meter condition or the state of the river. Drift-net sets with faulty or missing flow readings that also lacked information on the duration of the sampling period were removed (e.g., 1-10 July 1992 at the downstream Four Corners location). Samples that persisted for more than four hours were also removed from the CPUE dataset because the accumulation of debris in the net negatively affected filtering efficiency. This included six samples from the downstream location and one set from the upstream location for Four Corners in 1993.

New flow-meter values were estimated, whenever possible, from temporally proximate sets conducted at the same sampling location under the same flow conditions. From these adjacent samples, a per-minute average of flow-meter revolutions was calculated and subsequently multiplied by the number of minutes (for the set in question) to obtain an estimated value of flow. On rare occasions, flow-meter readings were faulty for a week or more (e.g., 31 July-14 August 1993 at the upstream Four Corners location). The estimates of the volume of water sampled during those periods are less reliable than estimates for individual samples

We attempted to develop general empirical relationships among volume of water sampled, length of time sampled and mean daily discharge. This exercise was performed with the goal of developing an equation for estimating daily flow readings for years/sites lacking flow measures (1991 Four Corners; 1993 Mexican Hat; 1994 Four Corners and Mexican Hat). Regression analysis was used to evaluate the possibility of employing two models, linear and logarithmic (e.g., see Johnston et al., 1995) to determine relationships between the proportion of flow sampled (PF) and the proportion of time (out of 24 hours, PT) sampled daily. The value PF is equal to the volume of water sampled divided by total volume of water available and was determined from mean discharge. A second independent variable, mean daily discharge, Q (or, for the logarithmic model, ln[Q]), was added to these models after noting that an increase in discharge may decrease the proportion of flow sampled per unit time. During periods of high flow, the cross-sectional area of the river generally increased but drift-net size remained the same. Furthermore, collectors frequently relocated drift-nets to mesohabitats with a lower-water velocity in an effort to maximize net efficiency. This relocation usually resulted in the drift-nets set closer to the shore and away from the thalweg.

We tested four linear models, combining data for all years and sites where volume of water sampled had been measured. All four relationships were significant (i.e. $p < 0.05$); however, significance was due primarily to large sample size ($n = 379$) and not strength of relationship. In fact, R^2 values did not exceed 0.16, except for the logarithmic relationship that included both proportion time sampled and average discharge ($R^2 = 0.70$). This R^2 value was higher than expected and suggested that a considerable amount of variability in the amount of discharge being sampled can be explained by measured parameters. This resulted in the decision not to estimate flow on a daily basis for the five sampling periods that lacked flow measurements, but rather to estimate volume of water sampled during the entire individual sampling periods (n=5).

To do this, we tested the same four statistical models described above, using year/site totals for volume of water sampled and time sampled. In addition, we also examined the relationship between volume of water sampled and time sampled (i.e., not proportions).

Of these five predictive relationships, the most robust was the multiple logarithmic relationship:

$$\ln(PF) = 1.345 + 1.661\ln(PT)1.121\ln(\overline{Q})$$

with $R^2 = 0.86$ ($n = 11$; $F = 23.65$; $df = 2{,}8$; $p < 0.001$). From the above empirical relationship, total volume of water sampled for years/sites lacking direct measures were estimated (Table 1).

Catch-per-unit-effort (CPUE) was then determined by dividing the number of drifting fish caught by the volume of water sampled (100 m^3). As there were no notable differences in catch or catch rates among nets in any year at either site, those data were combined to yield one value for each parameter for each set. For years and sites where CPUE data were available (Table 1), catch rates for morning and evening sets on the same day were evaluated using a paired comparisons t-test. Catch rates were calculated for all species combined for this test. There was no statistically significant difference in catch rate between morning and evening sets ($t = 1.32$, $df = 107$, $p = 0.19$) so the number of fish caught and volume of water sampled were combined to yield a single catch rate for each species on a daily basis (daily CPUE).

Since daily flow could not be estimated (from models) for the five years/sites lacking flow measurements, daily CPUE's are only available for those years/sites where flow was measured directly. In 1993, daily CPUE values reported for the Four Corners site were from the upstream location only; volume of water sampled was not measured at the downstream Four Corners location. A mean catch rate was also calculated for each year/site by dividing the total catch for each species by the total volume of water sampled (mean annual CPUE). Mean annual CPUE values were determined for all years at both sites.

Relation of Drift CPUE to Flow Regime

We tested the hypothesis that characteristics of the flow regime were associated with the variation observed in drift density in larval red shiner (*Cyprinella lutrensis*), speckled dace (*Rhinichthys osculus*), and channel catfish (*Ictalurus punctatus*). These taxa were selected because they exhibited more variability in their drift than the other species collected and the sampling period encompassed the majority of their reproductive season. A set of descriptive hydrograph statistics was compiled for each year at each site from USGS discharge data obtained from the Four Corners, New Mexico and Bluff, Utah gauging stations. The statistics were calculated during the period of 1 January - 31 August each year (1991-1997) and were comprised of the following seven flow variables: maximum discharge (cubic feet per second, cfs), number of days discharge was greater than 2,500, 5,000, 8,000, and 10,000 cfs, and number of days discharge was less than 1,000 and 500 cfs. The drift variables selected were mean annual CPUE and maximum daily CPUE. For each species at each site, Pearson correlation coefficients (r) were calculated and evaluated between each drift variable and each flow variable. Data from all seven years of the study were included in analyses involving mean annual CPUE, while only five of seven were included in analyses involving maximum daily CPUE. (Daily CPUE values were not available for 1991 and 1994 at Four Corners or 1993 and 1994 at Mexican Hat). Analyses were performed at the 5% level of significance and assumptions of normality were tested using normal plots and Lilliefors tests of residuals.

While the seven hydrograph variables were interrelated, they characterized different aspects of the hydrograph (any of them may be important for reproduction of the three species examined). Additionally, there were enough non-significant correlation coefficients among comparisons of hydrograph variables to warrant inclusion of the entire group. The variables selected were chosen to determine if there was a threshold discharge or a level of flow above (or below) at which reproduction was markedly improved. To aid in interpreting the results of the correlation analysis, the variance-covariance matrix for hydrograph variables was examined and Pearson correlation coefficients calculated among them.

Daily CPUE values were also compared to daily flow patterns. The mean daily discharge within and between years was quite variable. Large rain events augmented flows briefly and many were easily detected on the hydrograph. However, many smaller events only caused very minor increases in flow but resulted in noticeable increases in stream turbidity and instream debris levels. A rainstorm event is defined as resulting in noticeable increases in levels of turbidity and debris at the sampling station even if measured increases in flow were negligible.

RESULTS

Summary of Data Collection

A total of 17,525 individuals representing 12 fish species was collected in drift-nets over the seven years of the study (Table 3) of which 13,683 (78.1%) were drifting larval fish. Channel catfish was the most abundant of the drifting larval fish (n=4,384), followed by speckled dace (n=3,901), red shiner (n=2,716), flannelmouth sucker (*Catostomus latipinnis*; n=1,448), bluehead sucker (*Catostomus discobolus*; n=954), fathead minnow (*Pimephales promelas*; n=260), common carp (*Cyprinus carpio*; n=15), and Colorado pikeminnow (n=5). A single roundtail chub (*Gila robusta*) was collected but its size indicated that it was an incidental capture. Fish species collected that were not represented by drifting larvae (i.e., black bullhead [*Ameiurus melas*], western mosquitofish [*Gambusia affinis*], and largemouth bass [*Micropterus salmoides*]) comprised about 0.1% of the total catch.

The percentage of individuals that were drifting versus incidental varied between species, sites, and years with the exception of Colorado pikeminnow (all individuals collected were drifting larvae). The majority of red shiner taken during this study were classified as drifting fish (87%); the proportion was the same at both Four Corners and Mexican Hat. This high percentage was largely driven by large collections of red shiner in 1991 and 1995 when 98% of individuals were classified as drifting. The percentage of red shiner that were drifting in other years ranged from 28% in 1992 to 81% in 1996.

Most common carp were classified as incidental captures (89%) and this pattern was maintained annually at both sites with the exception of 1991 when the majority of individuals (56%) were drifting. The percentage of drifting fathead minnow collected during the period of study (47%) differed between sites (Mexican Hat-16% versus Four Corners-63%). This was primarily the result of a large collection of non-drifting fathead minnow at Mexican Hat in 1993. Most speckled dace collected were drifting (64%) with minimal variation between sites or years. Likewise, the majority of flannelmouth sucker collected were classified as drifting (68%). However, the Four Corners site had a relatively higher percentage of drifting flannelmouth sucker (89%) than did Mexican Hat (46%). This difference was caused by a large collection of non-drifting flannelmouth sucker collected at Mexican Hat in 1993. Nearly all bluehead sucker (95%) and channel catfish (98%) collected were drifting individuals and this trend did not vary temporally or spatially.

Rank order of drifting fish varied by site (Figure 2) with speckled dace being the most abundant fish at Four Corners (38%) and channel catfish numerically dominating the catch at Mexican Hat (54%). More drifting fish were collected at Four Corners (n=7,578) than at Mexican Hat (n=6,105). Red shiner, fathead minnow, speckled dace, flannelmouth sucker, and bluehead sucker were all captured more frequently at Four Corners than at Mexican Hat while the converse was true for channel catfish.

The number of drifting fish collected annually during this study ranged between 968 and 2,042 except in 1995 when 4,441 individuals were taken (Figure 3). Red shiner was the most frequently collected fish in 1991, speckled dace numerically dominated two years (1993 and 1995),

Table 3. List of all fish species captured in drift-nets for the years 1991-1997 at the Mexican Hat site (a) and Four Corners site (b); total number of individuals collected (T), total number of drifting individuals collected (D), and percent of total that were drifting (P) are listed.

(a) Mexican Hat site

	1991			1992			1993			1994			1995			1996			1997		
Species	T	D	**P**	T	D	**P**	T	D	**P**	T	D	**P**	T	D	**P**	T	D	**P**	T	D	**P**
CYPLUT	20	15	**75**	6	0	**0**	49	15	**31**	145	61	**42**	976	972	**100**	115	85	**74**	20	11	**55**
CYPCAR	3	1	**33**	0	0	-	58	1	**2**	32	3	**9**	5	0	**0**	0	0	-	3	0	**0**
GILROB	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	1	0	**0**
PTYLUC	0	0	-	0	0	-	2	2	**100**	0	0	-	2	2	**100**	0	0	-	0	0	-
PIMPRO	17	5	**29**	1	1	**100**	106	4	**4**	16	4	**25**	15	9	**60**	11	7	**64**	27	0	**0**
RHIOSC	75	50	**67**	55	46	**84**	446	409	**92**	344	226	**66**	294	235	**80**	4	3	**75**	59	31	**53**
CATLAT	63	26	**41**	64	58	**91**	503	144	**29**	245	146	**60**	153	95	**62**	2	1	**50**	0	0	-
CATDIS	1	1	**100**	5	5	**100**	36	36	**100**	21	20	**95**	52	51	**98**	0	0	-	40	36	**90**
AMEMEL	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	1	0	**0**	2	0	**0**
ICTPUN	629	625	**99**	336	334	**99**	121	121	**100**	691	670	**97**	552	533	**97**	169	154	**91**	865	851	**98**
GAMAFF	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
MICSAL	1	0	**0**	1	0	**0**	0	0	-	0	0	-	0	0	-	1	0	**0**	0	0	-
Total	809	723	**89**	468	444	**95**	1,321	732	**55**	1,494	1,130	**76**	2,049	1,897	**93**	303	250	**83**	1,017	929	**91**

(b) Four Corners site

	1991			1992			1993			1994			1995			1996			1997		
Species	T	D	**P**	T	D	**P**	T	D	**P**	T	D	**P**	T	D	**P**	T	D	**P**	T	D	**P**
CYPLUT	840	825	**98**	30	10	**33**	180	157	**87**	100	7	**7**	302	281	**93**	320	266	**83**	18	11	**61**
CYPCAR	13	8	**62**	0	0	-	8	0	**0**	0	0	-	6	2	**33**	0	0	-	6	0	**0**
GILROB	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
PTYLUC	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	1	1	**100**	0	0	-
PIMPRO	107	60	**56**	22	18	**82**	140	92	**66**	13	7	**54**	43	34	**79**	21	13	**62**	18	6	**33**
RHIOSC	383	191	**50**	218	117	**54**	1,072	477	**45**	515	283	**55**	1,855	1,398	**75**	80	61	**76**	661	374	**57**
CATLAT	182	136	**75**	353	339	**96**	86	77	**90**	9	8	**89**	416	389	**94**	6	2	**33**	45	27	**60**
CATDIS	10	9	**90**	19	19	**100**	104	98	**94**	38	37	**97**	333	328	**99**	2	1	**50**	344	313	**91**
AMEMEL	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	4	0	**0**
ICTPUN	91	90	**99**	23	21	**91**	46	45	**98**	308	308	**100**	113	112	**99**	530	500	**94**	22	20	**91**
GAMAFF	0	0	-	1	0	**0**	0	0	-	1	0	**0**	2	0	**0**	0	0	-	1	0	**0**
MICSAL	0	0	-	0	0	-	0	0	-	1	0	**0**	1	0	**0**	0	0	-	1	0	**0**
Total	1,626	1,319	**81**	666	524	**79**	1,636	946	**58**	985	650	**66**	3,071	2,544	**83**	960	844	**88**	1,120	751	**67**

Table 3 (continued). List of all fish species captured in drift-nets for the years 1991-1997 at the Mexican Hat and Four Corners sites combined (c), and a summary of all fish species captured in drift-nets between 1991-1997 for the Mexican Hat site, the Four Corners site, and both sites (d); total number of individuals collected (T), total number of drifting individuals collected (D), and percent of total that were drifting (P) are listed.

(c) Both sites combined

	1991			1992			1993			1994			1995			1996			1997		
Species	T	D	**P**	T	D	**P**	T	D	**P**	T	D	**P**	T	D	**P**	T	D	**P**	T	D	**P**
CYPLUT	860	840	**98**	36	10	**28**	229	172	**75**	245	68	**28**	1,278	1,253	**98**	435	351	**81**	38	22	**58**
CYPCAR	16	9	**56**	0	0	**-**	66	1	**2**	32	3	**9**	11	2	**18**	0	0	**-**	9	0	**0**
GILROB	0	0	**-**	0	0	**-**	0	0	**-**	0	0	**-**	0	0	**-**	0	0	**-**	1	0	**0**
PTYLUC	0	0	**-**	0	0	**-**	2	2	**100**	0	0	**-**	2	2	**100**	1	1	**100**	0	0	**-**
PIMPRO	124	65	**52**	23	19	**83**	246	96	**39**	29	11	**38**	58	43	**74**	32	20	**63**	45	6	**13**
RHIOSC	458	241	**53**	273	163	**60**	1,518	886	**58**	859	509	**59**	2,149	1,633	**76**	84	64	**76**	720	405	**56**
CATLAT	245	162	**66**	417	397	**95**	589	221	**38**	254	154	**61**	569	484	**85**	8	3	**38**	45	27	**60**
CATDIS	11	10	**91**	24	24	**100**	140	134	**96**	59	57	**97**	385	379	**98**	2	1	**50**	384	349	**91**
AMEMEL	0	0	**-**	0	0	**-**	0	0	**-**	0	0	**-**	0	0	**-**	1	0	**0**	6	0	**0**
ICTPUN	720	715	**99**	359	355	**99**	167	166	**99**	999	978	**98**	665	645	**97**	699	654	**94**	887	871	**98**
GAMAFF	0	0	**-**	1	0	**0**	0	0	**-**	1	0	**0**	2	0	**0**	0	0	**-**	1	0	**0**
MICSAL	1	0	**0**	1	0	**0**	0	0	**-**	1	0	**0**	1	0	**0**	1	0	**0**	1	0	**0**
Total	2,435	2,042	**84**	1,134	968	**85**	2,957	1,678	**57**	2,479	1,780	**72**	5,120	4,441	**87**	1,263	1,094	**87**	2,137	1,680	**79**

(d) All years combined

	Mexican Hat			Four Corners			Both Sites		
Species	T	D	**P**	T	D	**P**	T	D	**P**
CYPLUT	1,331	1,159	**87**	1,790	1,557	**87**	3,121	2,716	**87**
CYPCAR	101	5	**5**	33	10	**30**	134	15	**11**
GILROB	1	0	**0**	0	0	**-**	1	0	**0**
PTYLUC	4	4	**100**	1	1	**100**	5	5	**100**
PIMPRO	193	30	**16**	364	230	**63**	557	260	**47**
RHIOSC	1,277	1,000	**78**	4,784	2,901	**61**	6,061	3,901	**64**
CATLAT	1,030	470	**46**	1,097	978	**89**	2,127	1,448	**68**
CATDIS	155	149	**96**	850	805	**95**	1,005	954	**95**
AMEMEL	3	0	**0**	4	0	**0**	7	0	**0**
ICTPUN	3,363	3,288	**98**	1,133	1,096	**97**	4,496	4,384	**98**
GAMAFF	0	0	**-**	5	0	**0**	5	0	**0**
MICSAL	3	0	**0**	3	0	**0**	6	0	**0**
Total	7,461	6,105	**82**	10,064	7,578	**75**	17,525	13,683	**78**

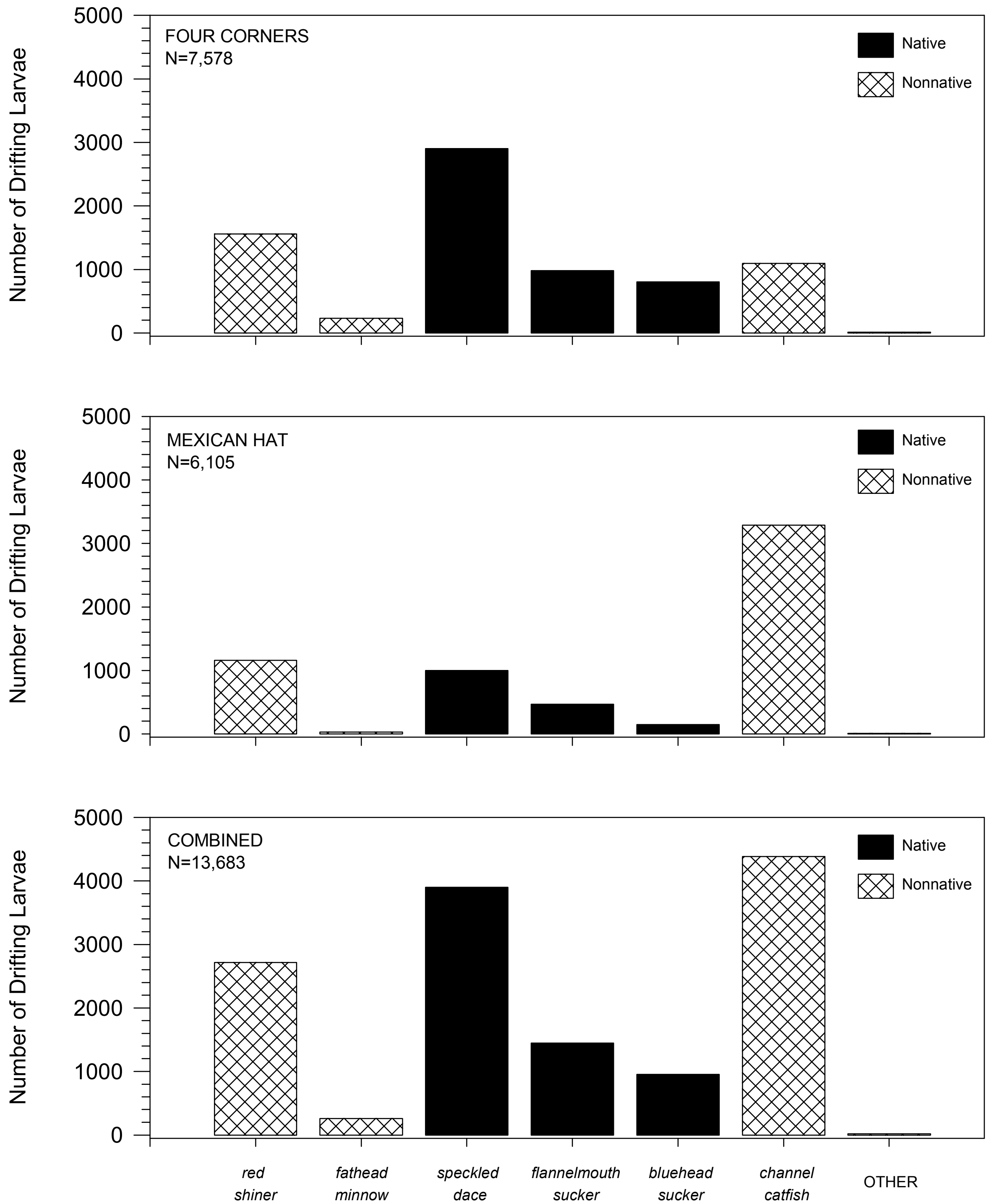

Figure 2. Number of drifting larvae collected at Four Corners, Mexican Hat, and the total collected at both sites from 1991-1997.

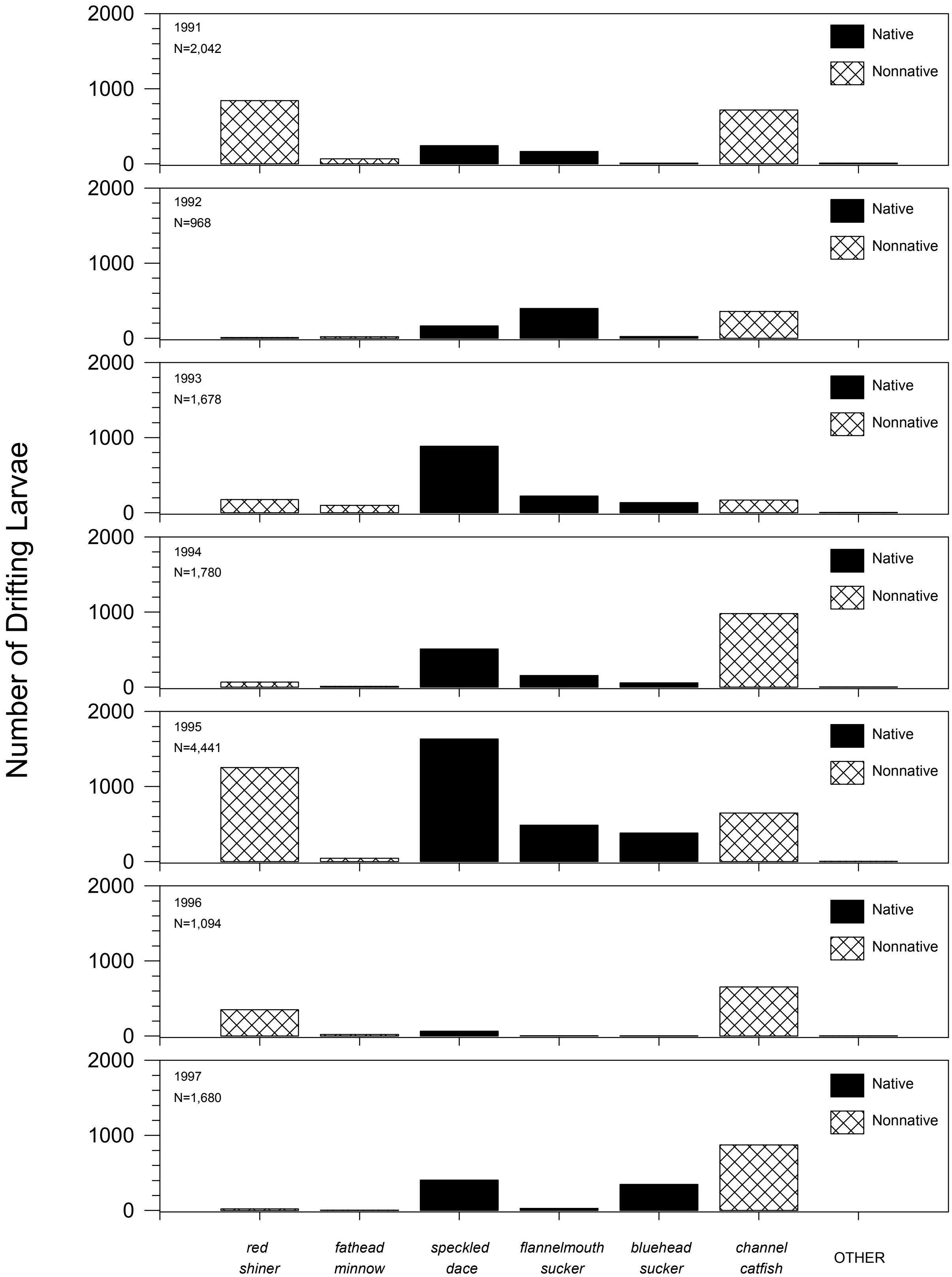

Figure 3. Number of drifting larvae collected at both sampling localities from 1991-1997.

flannelmouth sucker ranked first in abundance in 1992, and channel catfish was the most abundant in 1994, 1996, and 1997. While rank order and abundance of species varied between years, red shiner, speckled dace, and/or channel catfish typically dominated the catch. Red shiner and channel catfish comprised a large portion of the total catch in both 1991 and 1996; other species were represented by notably fewer individuals. The species-specific relative abundance of fish collected in 1993 was generally equal except for speckled dace. In 1992, 1994, and 1997 speckled dace, flannelmouth sucker, bluehead sucker, and channel catfish numerically dominated the catch. Speckled dace was less abundant relative to channel catfish numbers for all three years. However, flannelmouth sucker was notably more abundant in 1992 than in 1997 while the reverse was true for bluehead sucker. The abundance of all species, especially red shiner and speckled dace, was relatively high in 1995.

A portion of the annual differences in species abundance was the result of variation in the numbers of each species collected at each site (Figures 4 and 5). The Four Corners site was generally dominated by native fishes (e.g., speckled dace, flannelmouth sucker, and bluehead sucker). An exception to this observation was in 1991 when a large number of red shiner was collected at that site. The trend at Mexican Hat was the exact opposite with channel catfish and, to a lesser degree, red shiner numerically dominating the annual catch. In 1993 and 1994, moderate numbers of drifting speckled dace and flannelmouth sucker were collected at Mexican Hat.

Mean Annual and Maximum Daily Catch-Per-Unit-Effort (CPUE)

Mean annual CPUE of the six most abundant species varied considerably but annual differences in maximum daily CPUE were much greater (often an order of magnitude). While mean annual CPUE and maximum daily CPUE appeared moderately related, there were exceptions to this general trend. The two catch rates were different measures of larval density or reproduction. Maximum daily CPUE was a gauge of reproductive intensity on a short time scale, while mean annual CPUE was a measure of reproduction for the summer sampling period (i.e., July and August) and so the latter value potentially included non-reproductive periods. However, all species analyzed had a relatively protracted spawning period that, over the tenure of the study, included most of the summer.

Both mean annual and daily maximum CPUE for all species analyzed were variable between sites and years (Figure 6). Mean annual CPUE for red shiner peaked at the Four Corners site in 1991 but was also elevated in 1995 and 1996. Maximum daily CPUE of red shiner varied considerably between years at Four Corners and included a relatively high value in 1993. At Mexican Hat, annual red shiner catch rates were relatively low except in 1995 and 1996. Fathead minnow mean annual CPUE was stable across years and sites with the exception of a large catch at Four Corners in 1991 (Figure 7). Maximum daily CPUE of fathead minnow reached its highest levels during 1995 and 1996 at both sites but was still low compared to other species. Speckled dace mean annual CPUE exhibited considerable annual variation at both sites but was lowest in 1992 and 1996 when few individuals were collected at either site (Figure 8). The maximum daily CPUE of speckled dace achieved its highest level at both sites during 1997.

Flannelmouth sucker mean annual catch rates were highest during 1991, 1992, and 1995 at Four Corners and during 1993, 1994, and 1995 at Mexican Hat (Figure 9). Catch rates of flannelmouth sucker at Mexican Hat were considerably lower than those recorded at Four Corners. Maximum daily CPUE of flannelmouth sucker was highest in 1992 and 1995 at Four Corners and 1995 in Mexican Hat. Drifting bluehead sucker was most abundant during the summers of 1995 and 1997 at both sites (Figure 10). Both mean annual and daily maximum CPUE of bluehead sucker was higher at Four Corners than at Mexican Hat. There was a large variation in the mean annual catch rate of channel catfish at Four Corners with 1991, 1994, and 1996 being the years when highest values were recorded (Figure 11). Maximum daily CPUE for channel catfish at Four Corners varied little except for 1996 when it achieved its greatest level. Channel catfish mean annual CPUE was

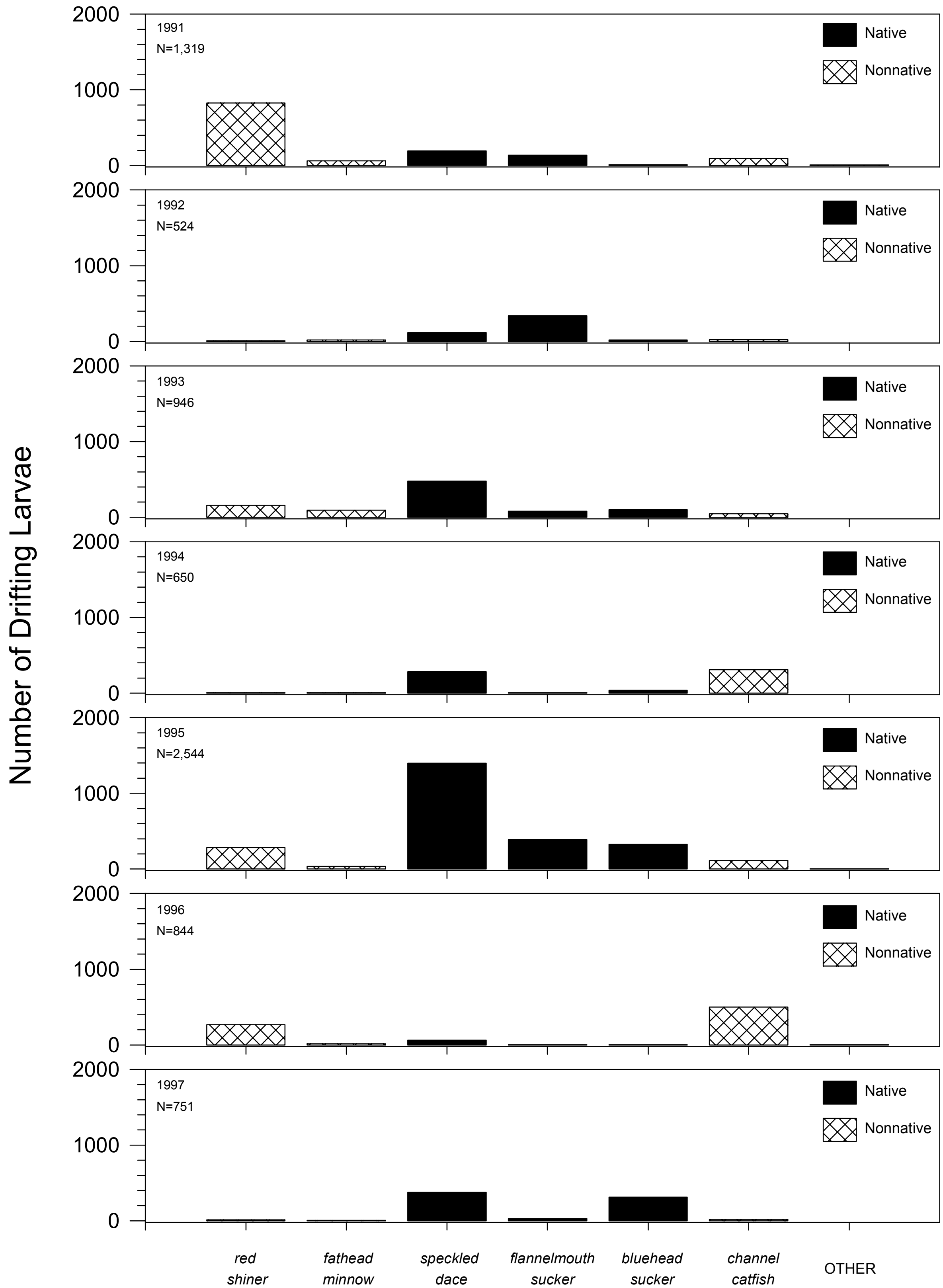

Figure 4. Number of drifting larvae collected at Four Corners from 1991-1997.

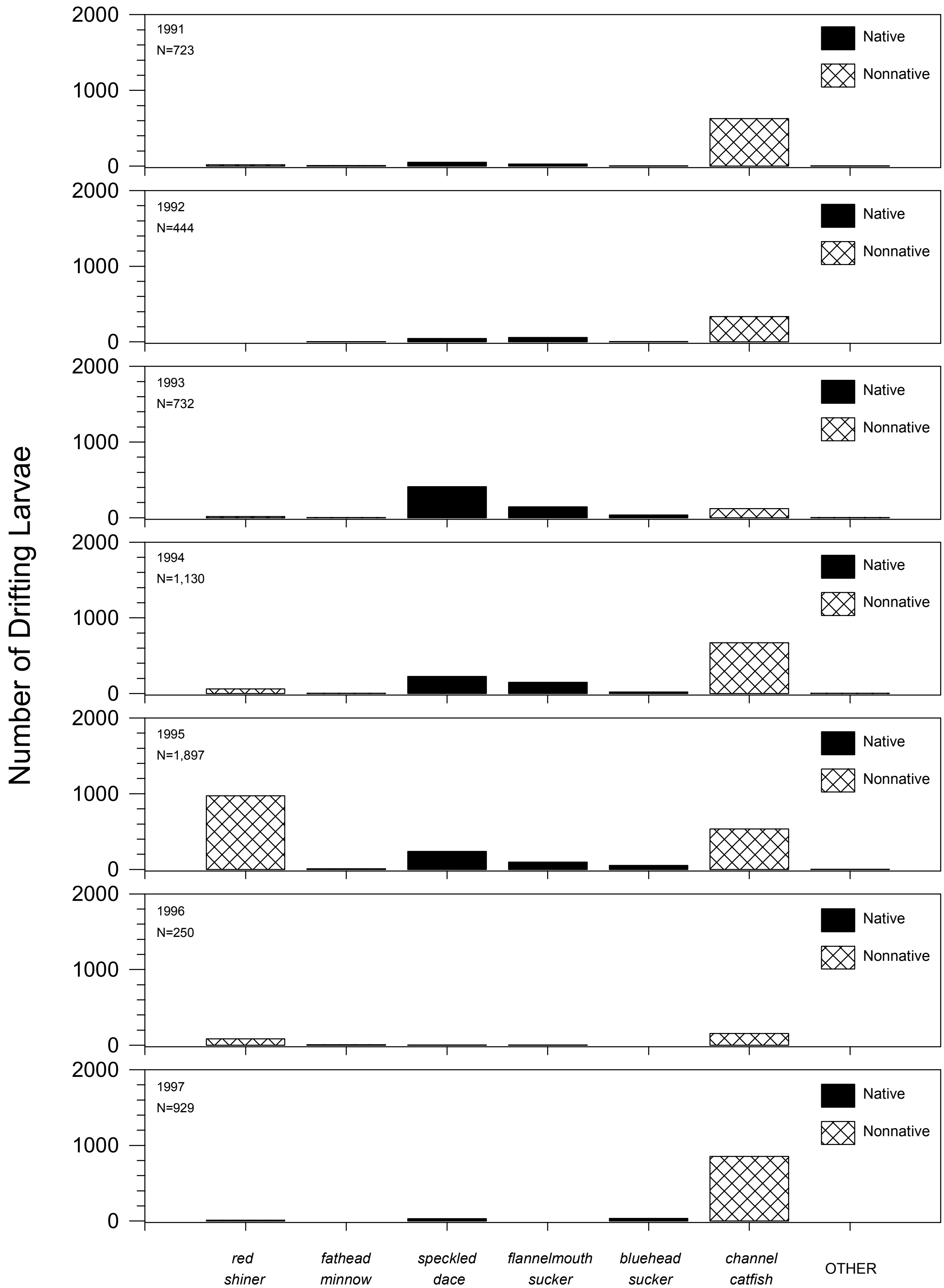

Figure 5. Number of drifting larvae collected at Mexican Hat from 1991-1997.

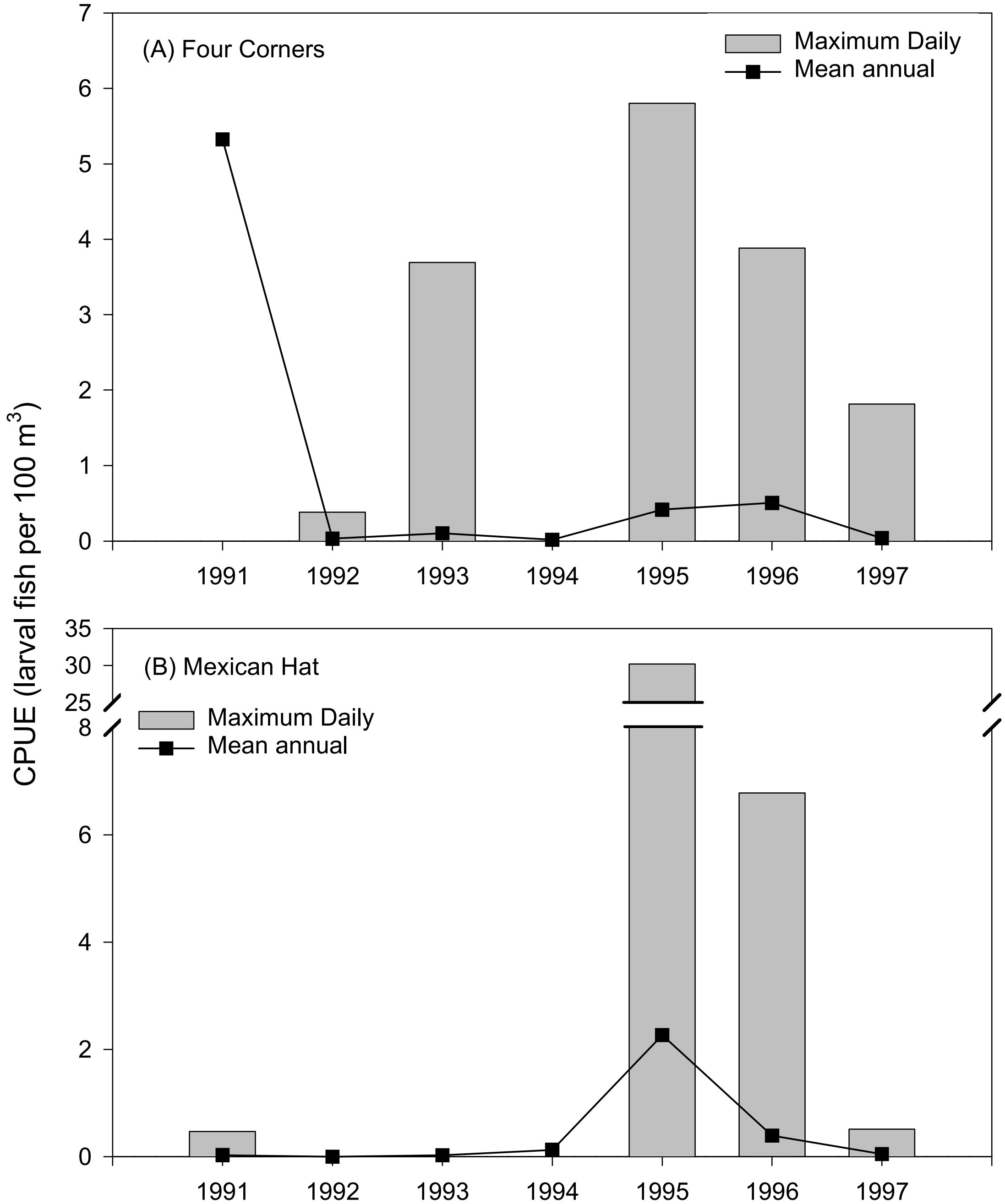

Figure 6. Mean annual and maximum daily CPUE for red shiner on the San Juan River at (A) Four Corners and (B) Mexican Hat. Maximum daily CPUE not available for 1991 and 1994 at Four Corners, nor for 1993 and 1994 at Mexican Hat.

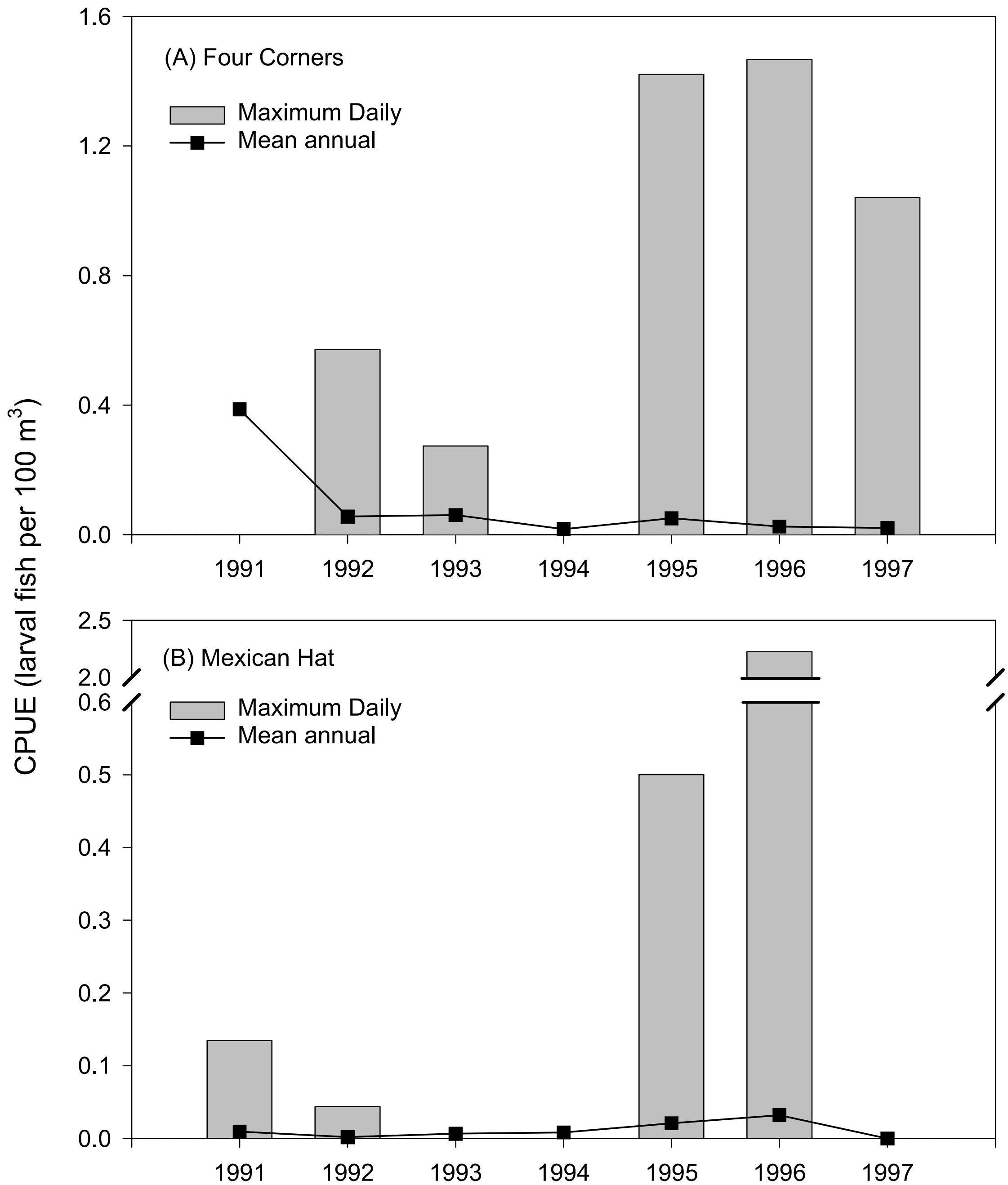

Figure 7. Mean annual and maximum daily CPUE for fathead minnow on the San Juan River at (A) Four Corners and (B) Mexican Hat. Maximum daily CPUE not available for 1991 and 1994 at Four Corners, nor for 1993 and 1994 at Mexican Hat.

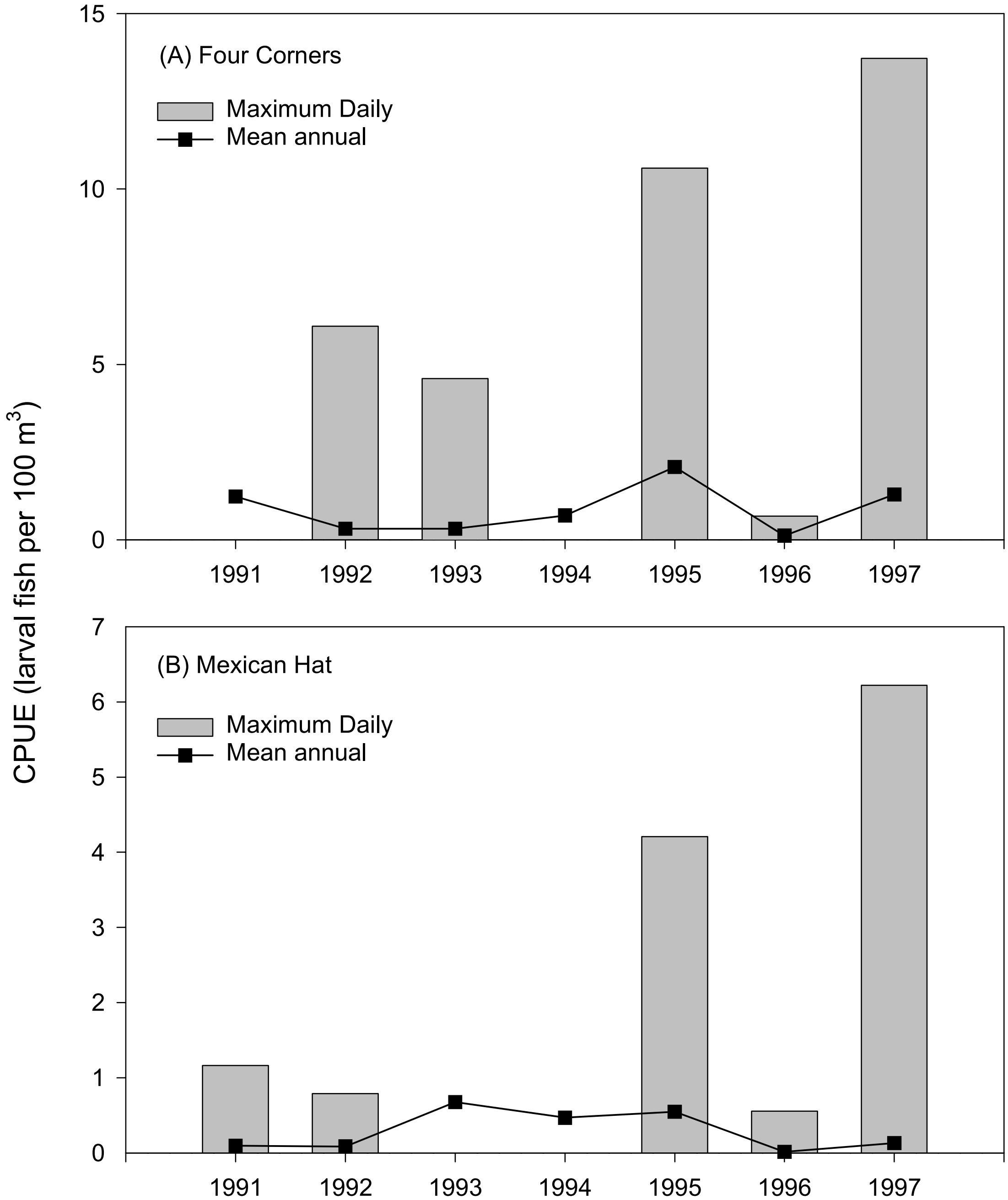

Figure 8. Mean annual and maximum daily CPUE for speckled dace on the San Juan River at (A) Four Corners and (B) Mexican Hat. Maximum daily CPUE not available for 1991 and 1994 at Four Corners, nor for 1993 and 1994 at Mexican Hat.

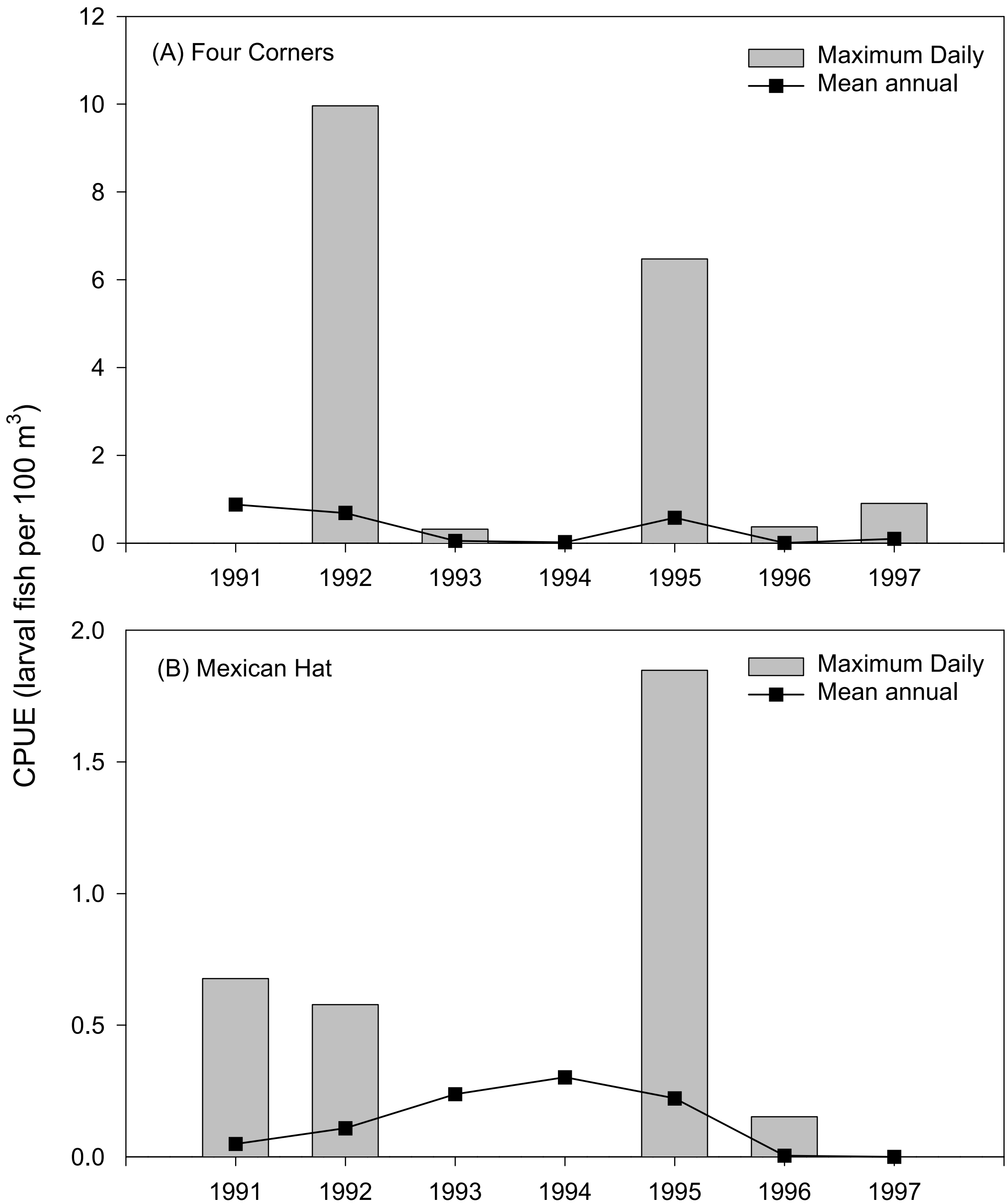

Figure 9. Mean annual and maximum daily CPUE for flannelmouth sucker on the San Juan River at (A) Four Corners and (B) Mexican Hat. Maximum daily CPUE not available for 1991 and 1994 at Four Corners, nor for 1993 and 1994 at Mexican Hat.

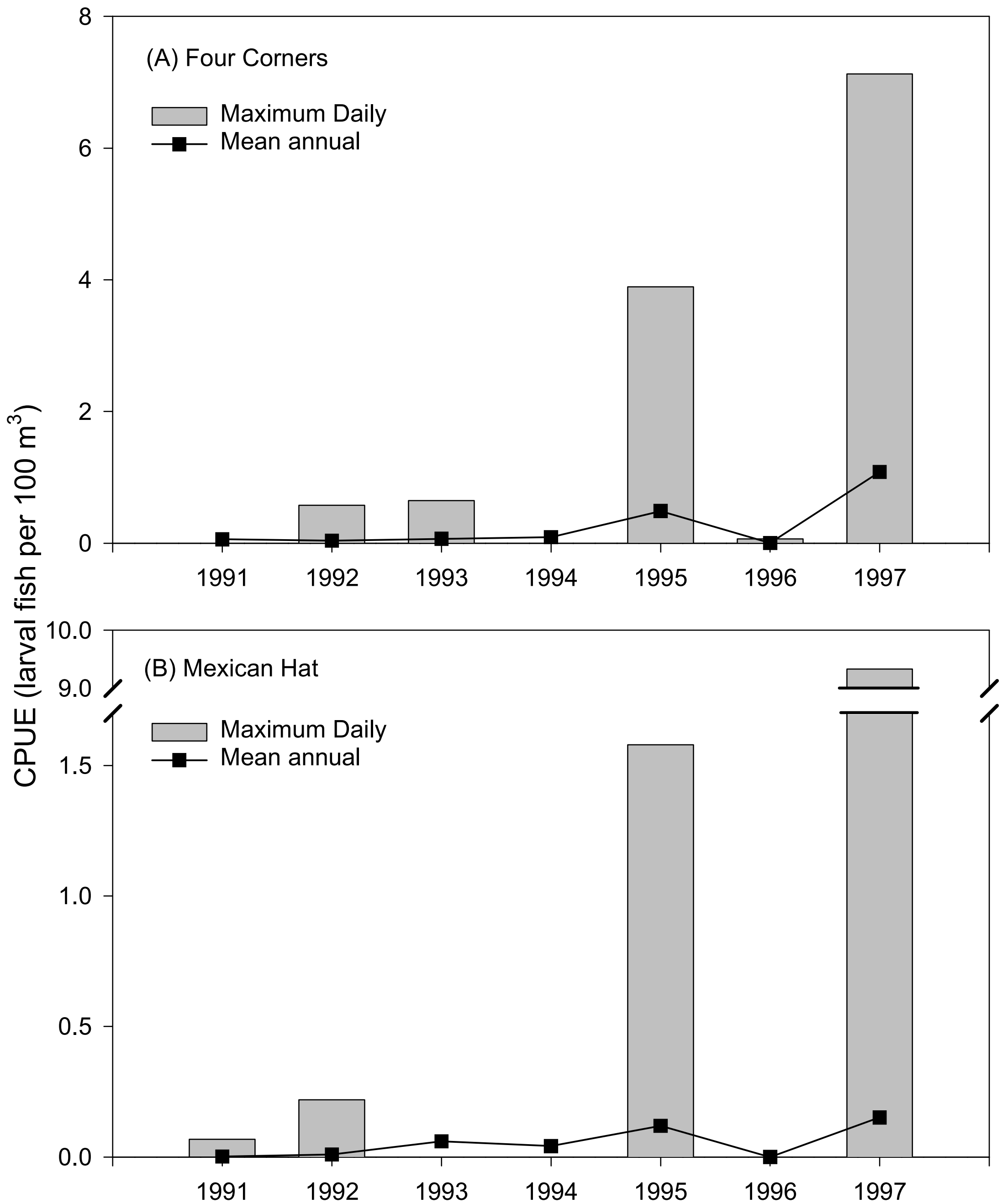

Figure 10. Mean annual and maximum daily CPUE for bluehead sucker on the San Juan River at (A) Four Corners and (B) Mexican Hat. Maximum daily CPUE not available for 1991 and 1994 at Four Corners, nor for 1993 and 1994 at Mexican Hat.

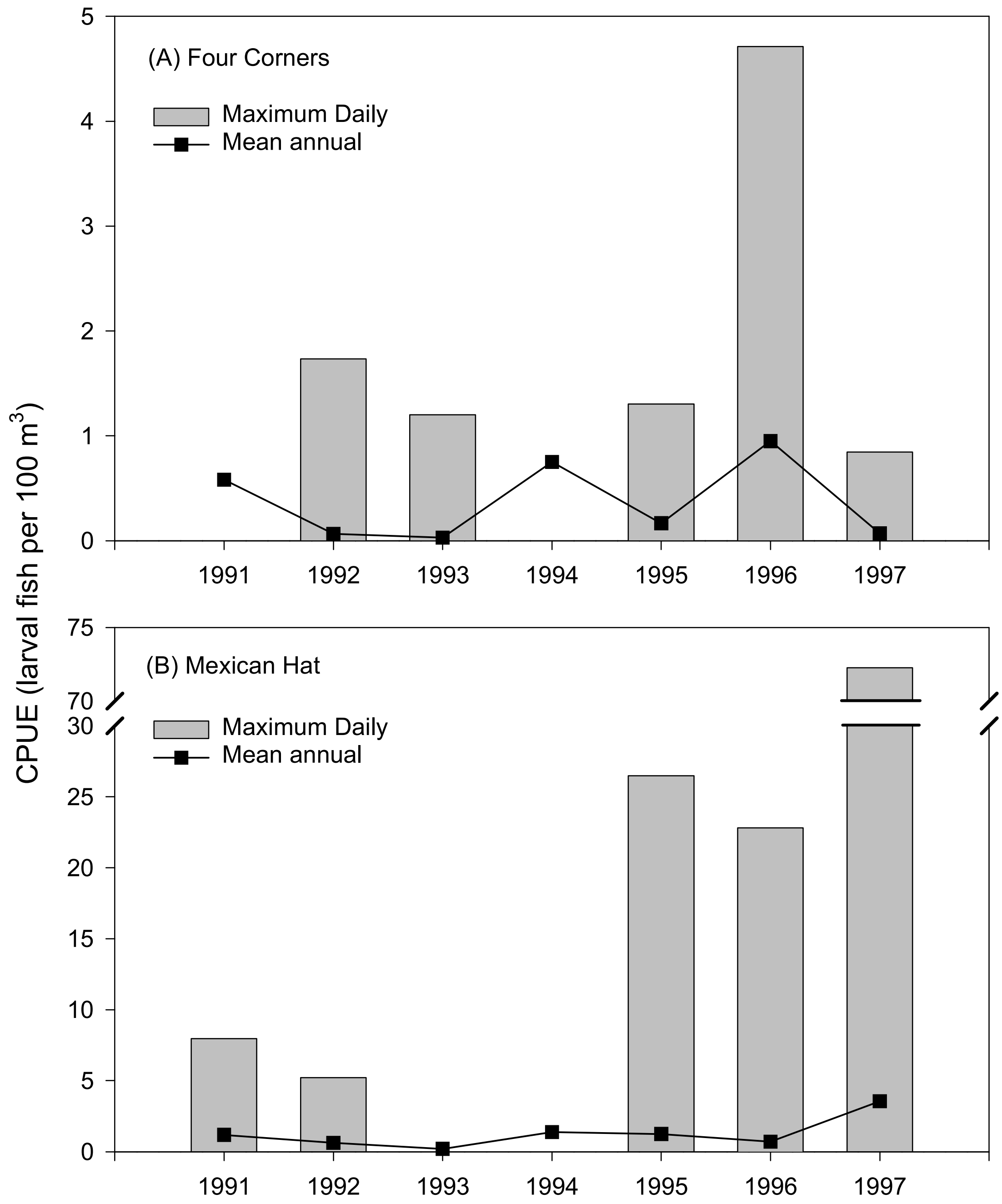

Figure 11. Mean annual and maximum daily CPUE for channel catfish on the San Juan River at (A) Four Corners and (B) Mexican Hat. Maximum daily CPUE not available for 1991 and 1994 at Four Corners, nor for 1993 and 1994 at Mexican Hat.

relatively constant at Mexican Hat during this study. Daily maximum channel catfish CPUE levels were higher in 1995 and 1996 than previous years but peaked in 1997 at almost three-times the previous maximum level.

Relationship of Annual Drift CPUE and Flow Regime

Seven hydrograph variables were determined from gauge information taken from Four Corners, New Mexico, and Bluff, Utah (near Mexican Hat) stations (Table 4). In general, 1991 and 1996 were low-flow years, 1992 and 1994 were periods of moderate flow on the San Juan River, and 1993, 1995, and 1997 were high-flow years (Figure 12). Flow exceeded 10,000 cfs only in 1993, 1995, and 1997. The peak flows in 1993 were only about 85% of those recorded in 1995 or 1997, but 1993 had more days with mean daily discharge above 2,500 (and especially 5,000 cfs) than any other year. In contrast, the number of high flow days in 1996 was exceptionally small not only during the spring runoff but also during the summer spawning period. Peak discharge in 1996 did not exceed 4,000 cfs at either Four Corners or Bluff, and there were about twice as many days below 500 cfs as was recorded during the next driest year. Although peak flows in 1994 were 10,000 cfs at Four Corners, there were a moderate number of days when flow was <500 cfs. While trends in high and low-flow years were mirrored at both sites, peak flows at Bluff did not exhibit the magnitude or duration of those observed at Four Corners.

While there was a high level of intercorrelation among the hydrograph variables examined (Table 5) there were a number of variable pairs (at both locations) that were not significantly correlated. At Four Corners, number of days with average discharge greater than 5,000 cfs was not significantly correlated with days greater than 8,000 cfs, days greater than 10,000 cfs, or days less than 1,000 cfs. The number of days greater than 10,000 cfs was significantly correlated with only days greater than 8,000 and days less than 1,000 cfs. Number of days with discharge less than 500 cfs was not correlated with days greater than 8,000 and 10,000 cfs. Generally, number of days less than 500 (or 1,000) cfs and greater than 8,000 (or 10,000) cfs are measures of different phenomena, the former being more influenced by precipitation during the winter and spring while the latter is more affected by precipitation during summer. Correlation among variables for Bluff exhibited the same general pattern as observed at Four Corners. Number of days with average discharge less than 500 cfs was not significantly correlated with days greater than 5,000 cfs or days less than 1,000 cfs.

The absence in variation in Colorado pikeminnow larval density over the seven years precluded its inclusion in this analysis. Drift density of red shiner, channel catfish, and speckled dace were examined with hydrograph variables to determine if there were significant correlations. Correlation coefficients for two sites and two measures of catch rate (mean annual and maximum daily CPUE) were contrasted with each of the seven hydrograph variables and resulted in 84 correlation coefficients and corresponding hypothesis tests.

None of the correlation coefficients for red shiner CPUE and hydrograph variables were significantly different from zero. Several of the correlation coefficients for channel catfish and speckled dace were significantly different from zero. For channel catfish at Four Corners, mean annual CPUE was negatively correlated with number of days discharge was greater than 2,500 cfs and 5,000 cfs, and positively correlated with number of days discharge was less than 500 cfs (Figure 13). Maximum daily channel catfish CPUE was negatively correlated with maximum discharge and number of days discharge was greater than 2,500 cfs, and also positively correlated with number of days discharge was less than 500 cfs (Figure 14). For channel catfish at Mexican Hat, only the correlation coefficient for mean annual CPUE and number of days discharge was greater than 10,000 cfs was significant (Figure 15).

For speckled dace at Four Corners, mean annual CPUE was positively correlated with number of days discharge was greater than 10,000 cfs (Figure 16). Maximum daily CPUE was positively correlated with maximum discharge, number of days above 8,000 cfs, and number of days

Table 4. Seven hydrograph variables used in correlation analyses for Four Corners (A) and Bluff (B).

(A) Four Corners

Year	Maximum discharge (cfs)	Number of days discharge (cfs) greater than: 2,500	5,000	8,000	10,000	Less than: 1,000	500
1991	5,160	50	2	0	0	56	17
1992	8,900	86	54	3	0	33	7
1993	10,300	140	109	16	1	26	0
1994	10,000	67	49	13	0	35	17
1995	12,100	136	72	27	11	0	0
1996	3,540	36	0	0	0	49	30
1997	11,900	121	53	33	10	4	0

(B) Bluff

Year	Maximum discharge (cfs)	Number of days discharge (cfs) greater than: 2,500	5,000	8,000	10,000	Less than: 1,000	500
1991	4,530	55	0	0	0	53	11
1992	8,510	87	44	4	0	28	1
1993	9,650	149	113	14	0	28	4
1994	8,290	64	41	1	0	37	15
1995	11,600	140	68	19	6	0	0
1996	3,280	37	0	0	0	49	30
1997	11,300	124	53	24	8	4	0

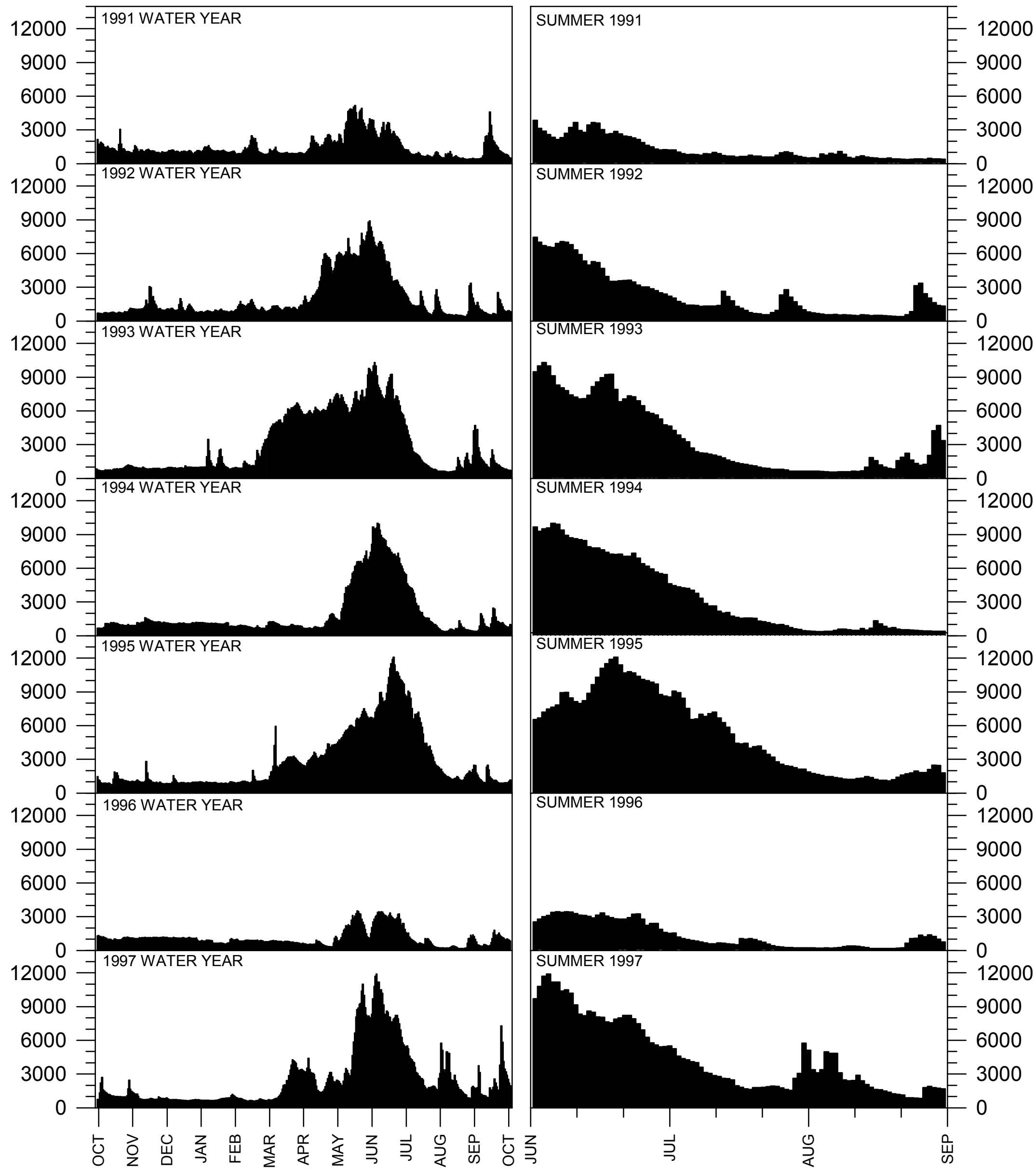

Figure 12. Hydrographs of the San Juan River (Four Corners Gauge) from 1991-1997 for the water year and the summer.

Table 5. Summary of results of correlation matrix for hydrograph variables (see Table 4) for Four Corners (A) and Bluff (B). Q = discharge; “+/-” indicates whether the correlation coefficient was positive or negative; NS = not significant; one asterisk (*) indicates that $p < 0.05$; two asterisks (**) indicates that $p < 0.01$.

(A) Four Corners

	Max.Number of days discharge (cfs) greater than: Q (cfs)	2,500	5,000	8,000	10,000	Less than: 1,000
Days > 2,500	+/*					
Days > 5,000	+/*	+/**				
Days > 8,000	+/*	+/*	+/NS			
Days > 10,000	+/NS	+/NS	+/NS	+/**		
Days < 1,000	-/**	-/*	-/NS	-/**	-/**	
Days < 500	-/**	-/**	-/*	-/NS	-/NS	+/*

(A) Bluff

	Max.Number of days discharge (cfs) greater than: Q (cfs)	2,500	5,000	8,000	10,000	Less than: 1,000
Days > 2,500	+/**					
Days > 5,000	+/*	+/**				
Days > 8,000	+/*	+/*	+/NS			
Days > 10,000	+/NS	+/NS	+/NS	+/**		
Days < 1,000	-/**	-/*	-/NS	-/**	-/*	
Days < 500	-/*	-/*	-/NS	-/NS	-/NS	+/NS

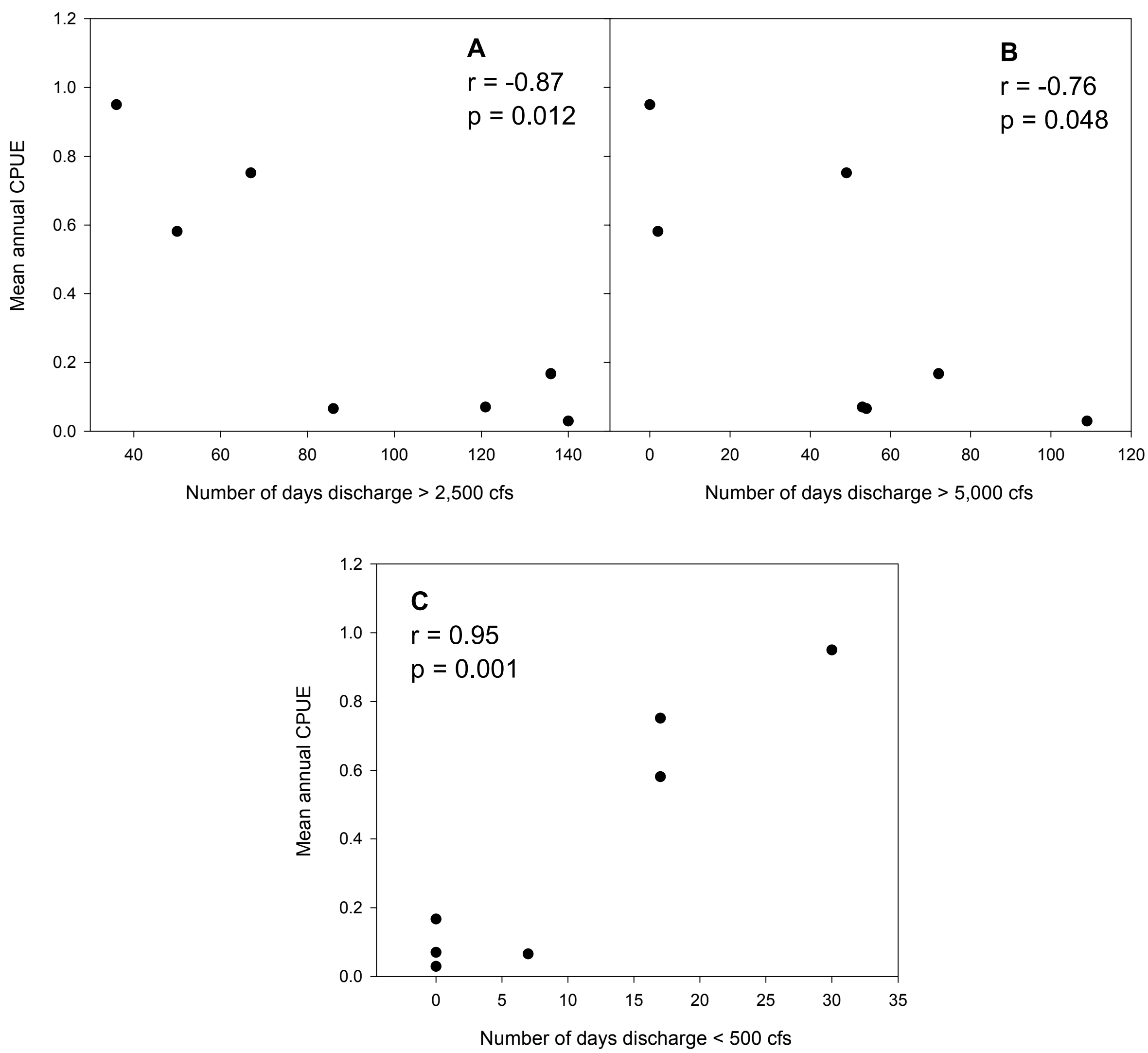

Figure 13. Mean annual CPUE (larval fish caught per 100 m^3 water sampled) for channel catfish vs. number of days discharge was greater than 2,500 cfs (A), greater than 5,000 cfs (B), and less than 500 cfs (C) at Four Corners for 1991-1997 (n = 7).

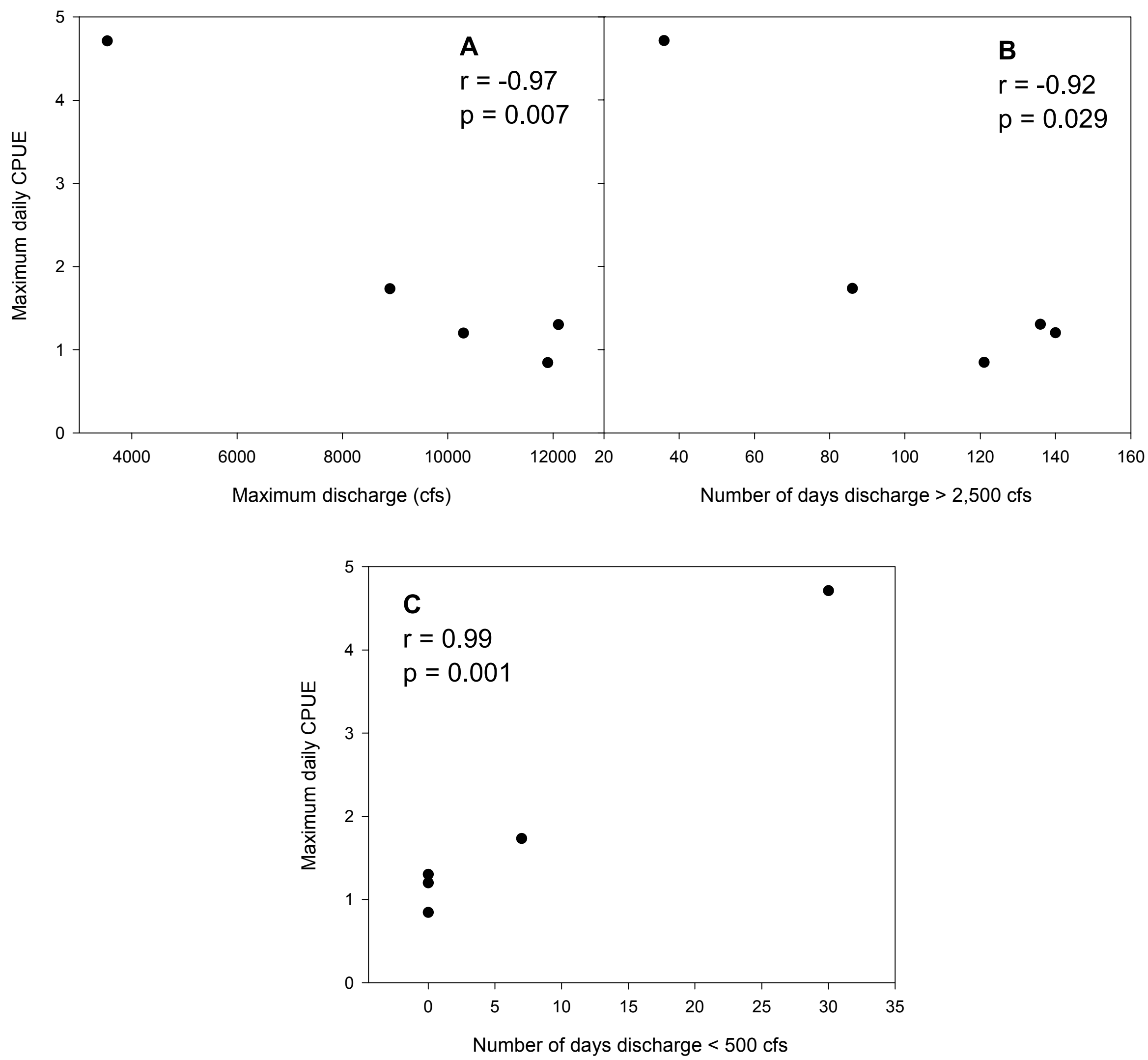

Figure 14. Maximum daily CPUE (larval fish caught per 100 m^3 water sampled) for channel catfish vs. maximum discharge in cfs (A), number of days discharge was greater than 2,500 cfs (B) and less than 500 cfs (C) at Four Corners for 1991-1997 (n = 5 for each analysis, as daily CPUE values were not available for 1991 and 1994).

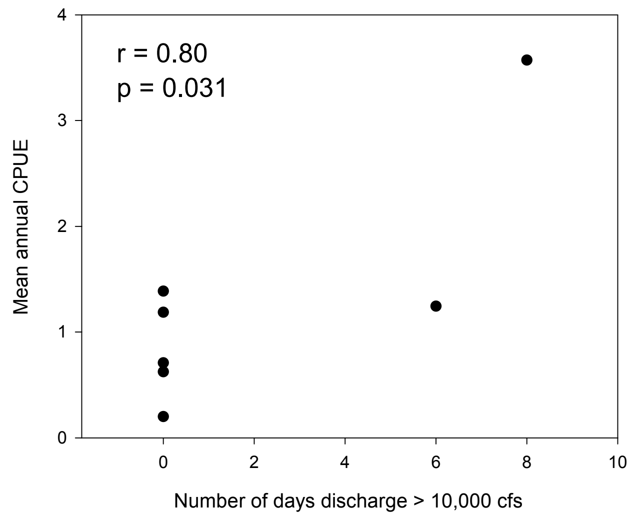

Figure 15. Mean annual CPUE (larval fish caught per 100 m^3 water sampled) for channel catfish vs. number of days discharge was greater than 10,000 cfs at Mexican Hat for 1991-1997 (n = 7).

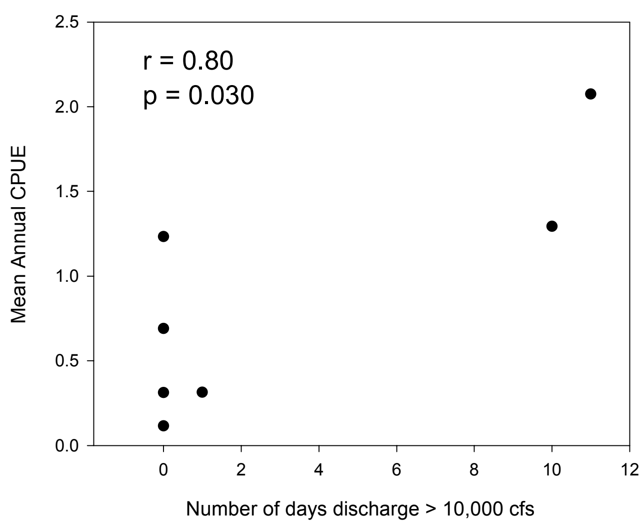

Figure 16. Mean annual CPUE (larval fish caught per 100 m^3 water sampled) for speckled dace vs. number of days discharge was greater than 10,000 cfs at Four Corners for 1991-1997 (n = 7).

above 10,000 cfs; and negatively correlated with number of days less than 1,000 cfs (Figure 17). At Mexican Hat, mean annual CPUE was positively correlated with number of days greater than 5,000 cfs (Figure 18), while maximum daily CPUE was positively and strongly ($r \geq 0.98$ for both) correlated with number of days with discharge greater than 8,000 cfs and 10,000 cfs (Figure 19).

Relationship of Daily Drift CPUE and Daily Flow by Year and Site

Information on CPUE of fishes was not available for 1991 at the Four Corners site. During 19-25 July 1991 and 29 July-5 August 1991 the two largest samples (n=193 and n=622, respectively) of red shiner were collected (Figure 20). Moderate increases in stream flow corresponded to these collections. During 1992, there was a modest spring runoff and several large summer rainstorms that resulted in considerable increases in stream flow. No red shiner were collected at the Mexican Hat collecting locality in 1992 and there were two very minor pulses of drifting larval red shiner at the Four Corners site that followed summer 1992 rainstorm events. Collections of red shiner in 1993 were also relatively low at both sites but again corresponded to increased stream flows caused by small summer rainstorms. When rainstorm events that resulted in increased catch were removed from the dataset (Figure 21), it was apparent that very few larval red shiner drifted during non-rainstorm periods. Several August 1995 rainstorms yielded slight increases in stream-flow, notable increases in instream debris levels, and nearly all (99.3%) drifting red shiner collected during that year. The early August rainstorms were small and resulted in minor increases in flow, but markedly increased levels of suspended sediments in the water column. The largest collection of drifting red shiner was taken in 1995 at Mexican Hat after a small rainstorm. Despite the low flow experienced in 1996, there were collections of drifting red shiner made in late summer during and following very minor rain events. A moderate number of red shiner (28.9%) were collected during non-rainstorm periods. There were few larval red shiner collected in 1997 immediately after mid-summer rainstorms.

The timing and pattern of collections of fathead minnow were similar to those observed for red shiner; most of the fish were collected during or after rainstorms (Figure 22) as opposed to non-rainstorm periods (Figure 23). The highest numbers of fathead minnow collected were taken in 1991 during the same two rainstorm events (19-25 July; n=14 and 29 July-5 August; n=45) that yielded large numbers of red shiner. Collections of larval fathead minnow were relatively consistent in magnitude at the Four Corners sampling locality in 1992, 1995, 1996, and 1997. During each of those years, all drifting larval fathead minnow occurred following summer rainstorms. Few individuals were taken in 1993 at Four Corners, but most (97.8%) were associated with rain events. Very few fathead minnow were captured in drift-nets at the Mexican Hat site in 1991, 1992, or 1993. The few individuals taken in 1995 followed minor increases in flow. The greatest density of fathead minnow at Mexican Hat occurred in 1996 following a summer (mid-July) rainstorm. There were no drifting individuals of this species captured at Mexican Hat in 1997.

Nearly all speckled dace at Four Corners in 1991 were taken during three rainstorms (9-15 July, n=13; 19-25 July, n=81; and 29 July-5 August, n=90) (Figure 24). This mirrored the pattern exhibited by red shiner and fathead minnow with the exception of the earlier capture of drifting larval speckled dace. A few drifting speckled dace were captured in drift-nets at Four Corners in 1992 following two July rain events; no individuals were taken during non-rainstorm periods (Figure 25). Very few speckled dace were collected at Mexican Hat in either 1991 or 1992. A large pulse of drifting speckled dace (n=304) was collected from 3-6 July 1993 at Mexican Hat during a period of increased flow (and debris levels). Sampling at the Four Corners station began on 6 July 1993 and speckled dace were collected there during non-rainstorm periods (34.6%) prior to several small August rains that apparently triggered increased drifting. Speckled dace were captured in drift-nets throughout 1995 at both sites but Four Corners produced many more individuals than Mexican Hat. Peaks in abundance at both sampling localities were recorded during and shortly after local rainstorm

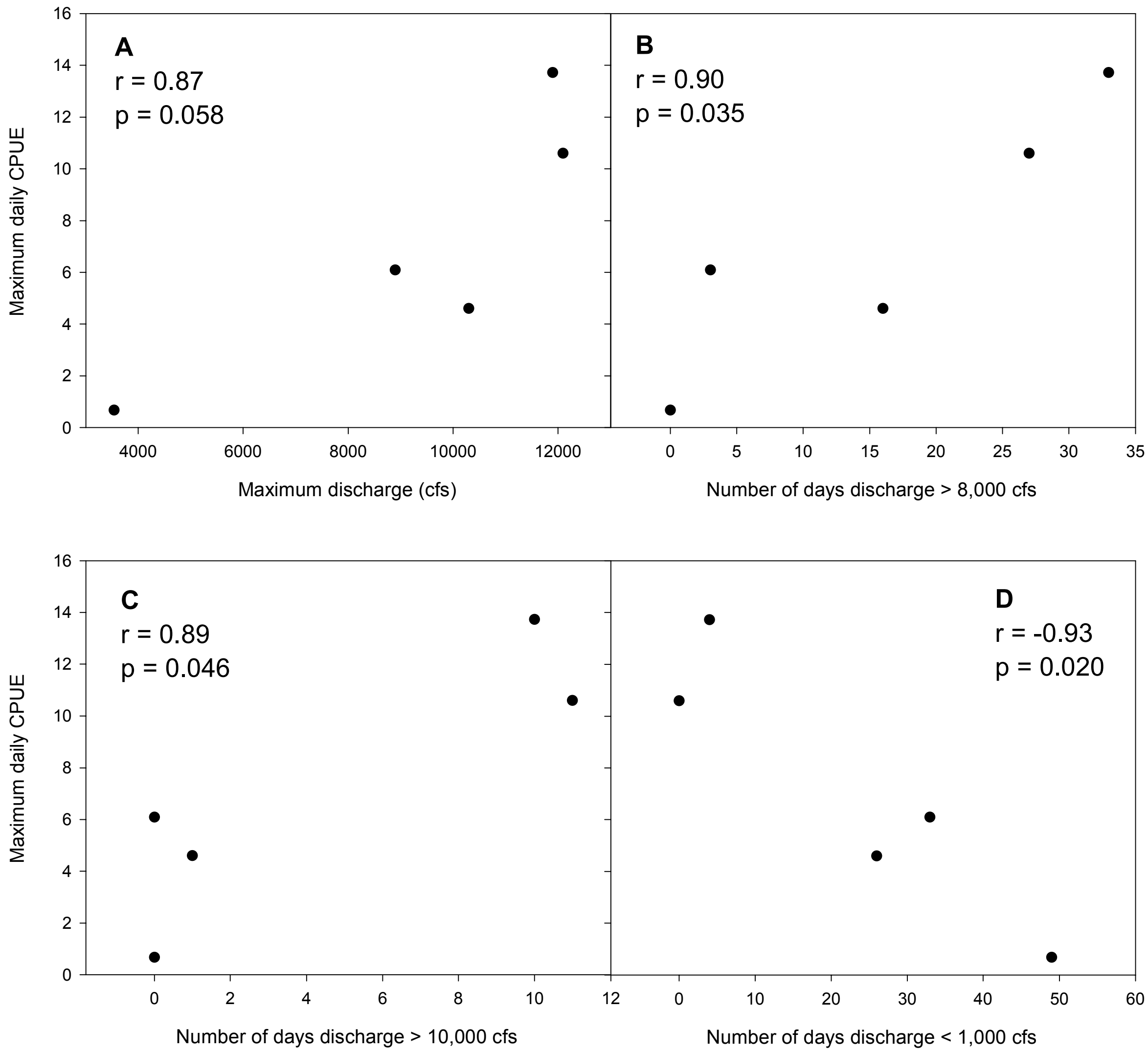

Figure 17. Maximum daily CPUE (larval fish caught per 100 m^3 water sampled) for speckled dace vs. maximum discharge in cfs (A), number of days discharge was greater than 8,000 cfs (B), greater than 10,000 cfs (C) and less than 1,000 cfs (D) at Four Corners for 1991-1997 (n = 5 for each analysis, as daily CPUE values were not available for 1991 and 1994).

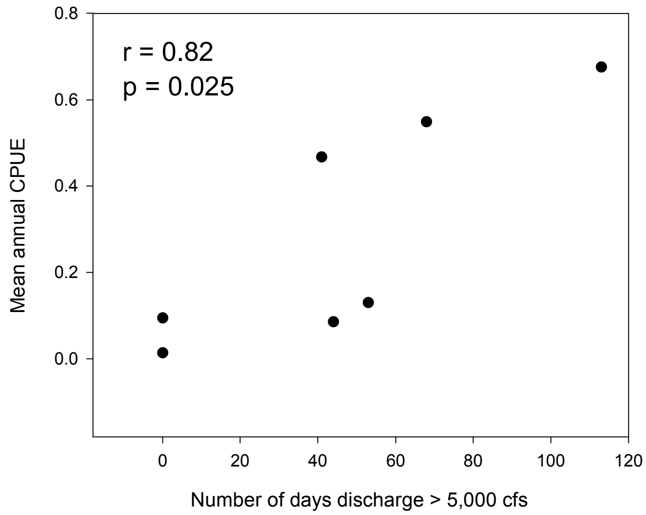

Figure 18. Mean annual CPUE (larval fish caught per 100 m^3 water sampled) for speckled dace vs. number of days discharge was greater than 5,000 cfs at Mexican Hat for 1991-1997 (n = 7).

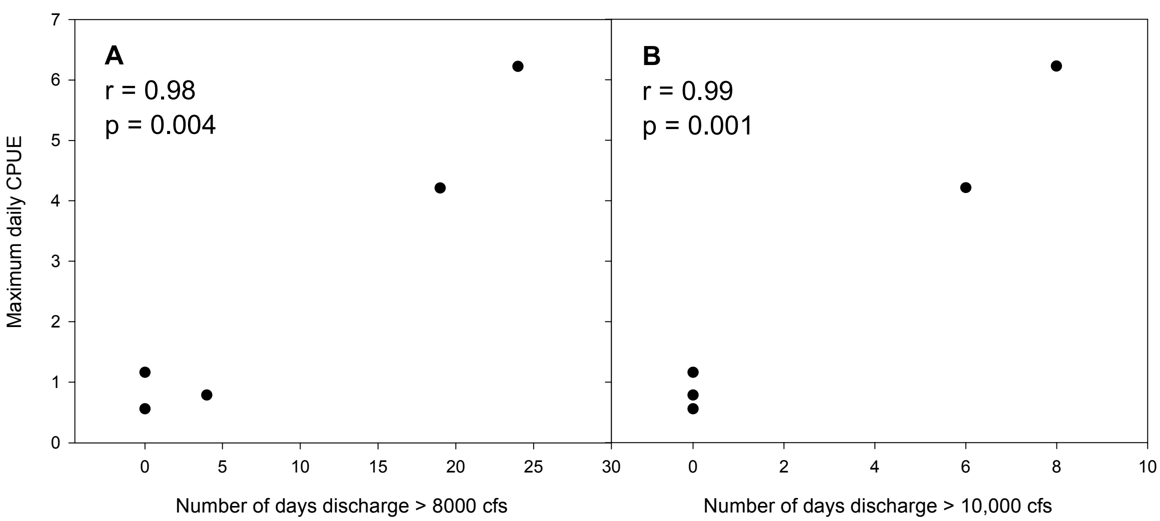

Figure 19. Maximum daily CPUE (larval fish caught per 100 m^3 water sampled) for speckled dace vs. number of days discharge was greater than 8,000 cfs (A) and greater than 10,000 cfs (B) at Mexican Hat for 1991-1997 (n = 5 for each analysis, as daily CPUE values were not available for 1993 and 1994).

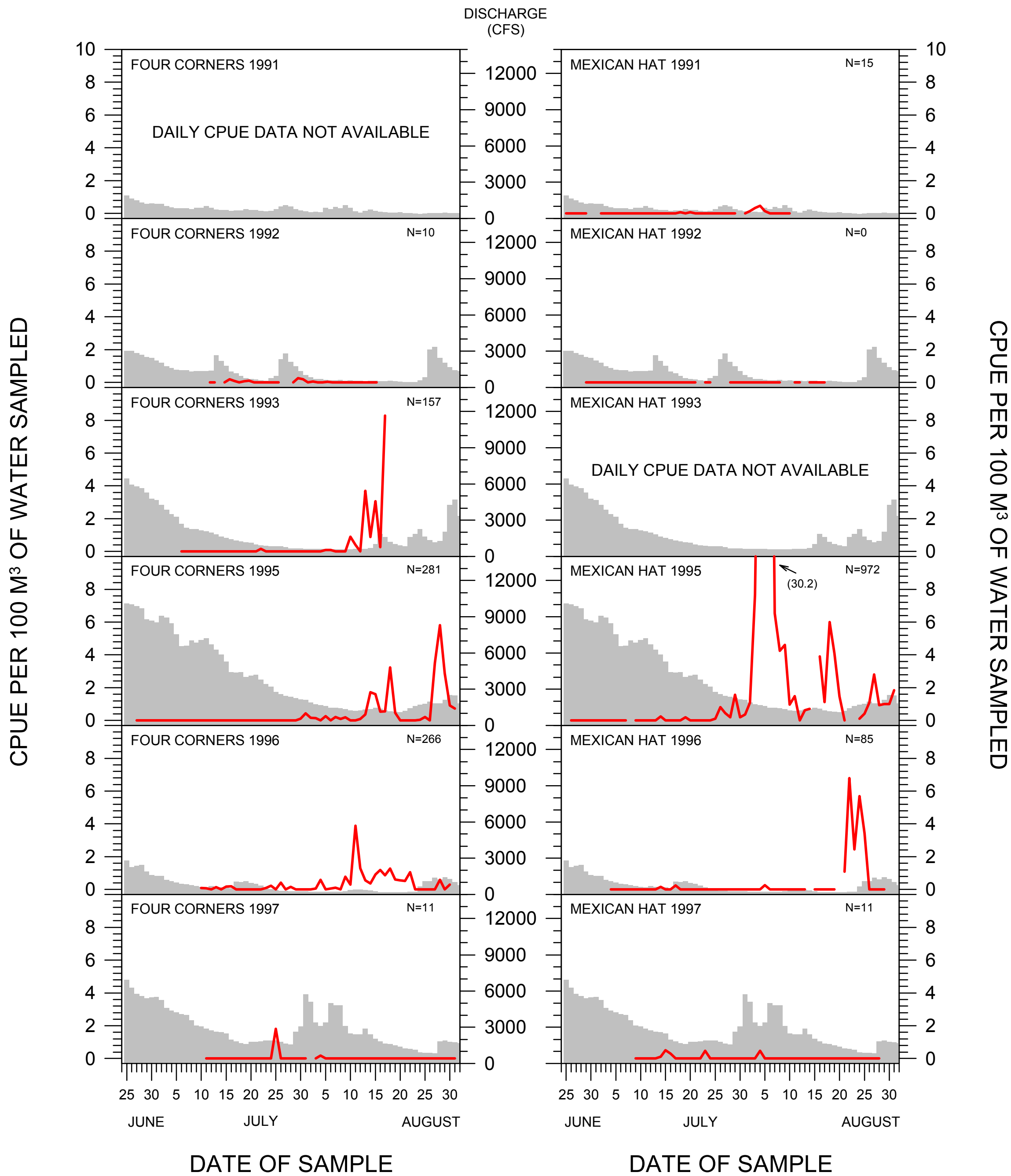

Figure 20. Red shiner CPUE at Four Corners and Mexican Hat from 1991-1993 and 1995-1997. Bar graph in background is discharge, while line graph in foreground is CPUE.

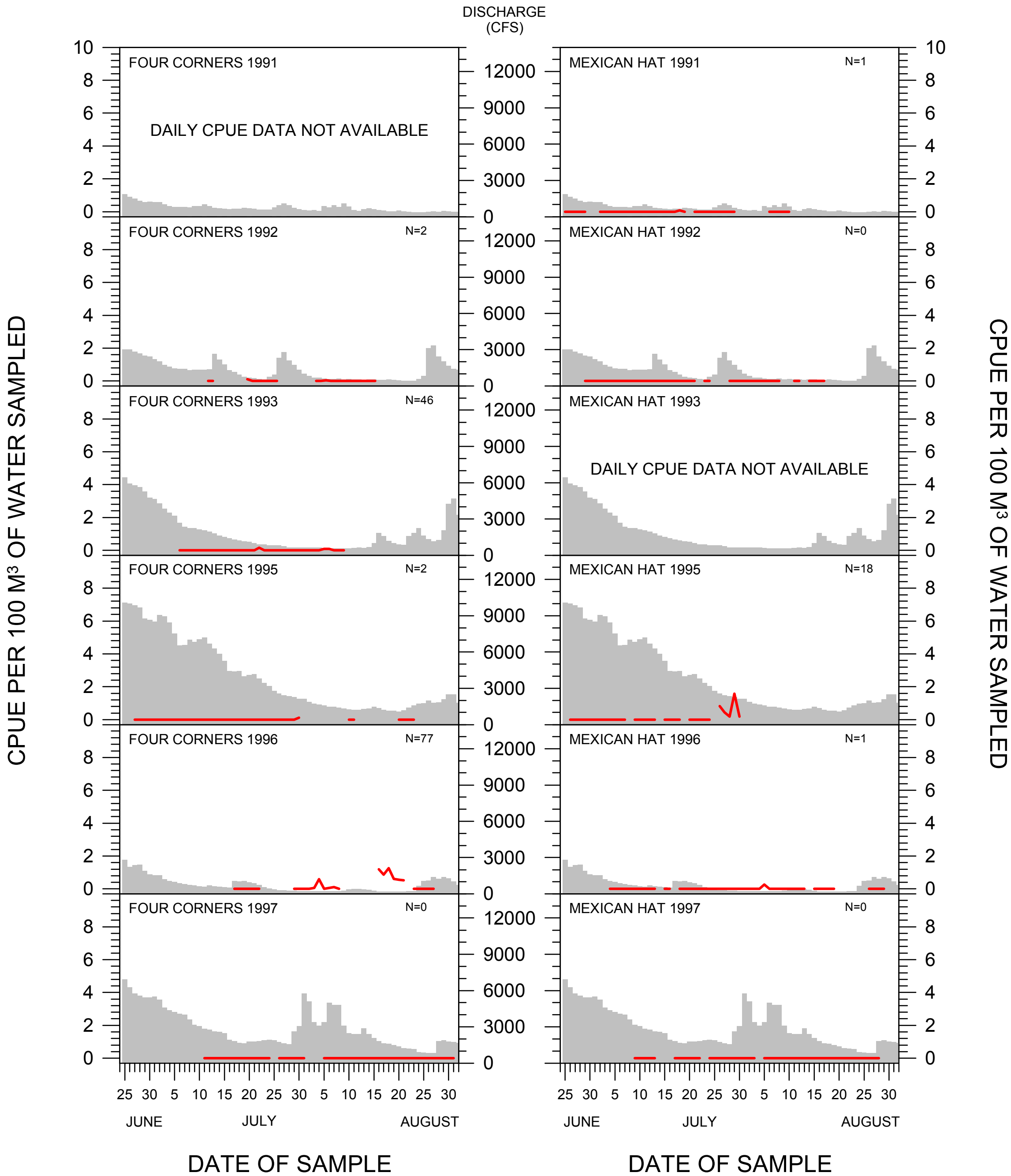

Figure 21. Red shiner CPUE (rainstorm events removed) at Four Corners and Mexican Hat from 1991-1993 and 1995-1997. Bar graph in background is discharge, while line graph in foreground is CPUE.

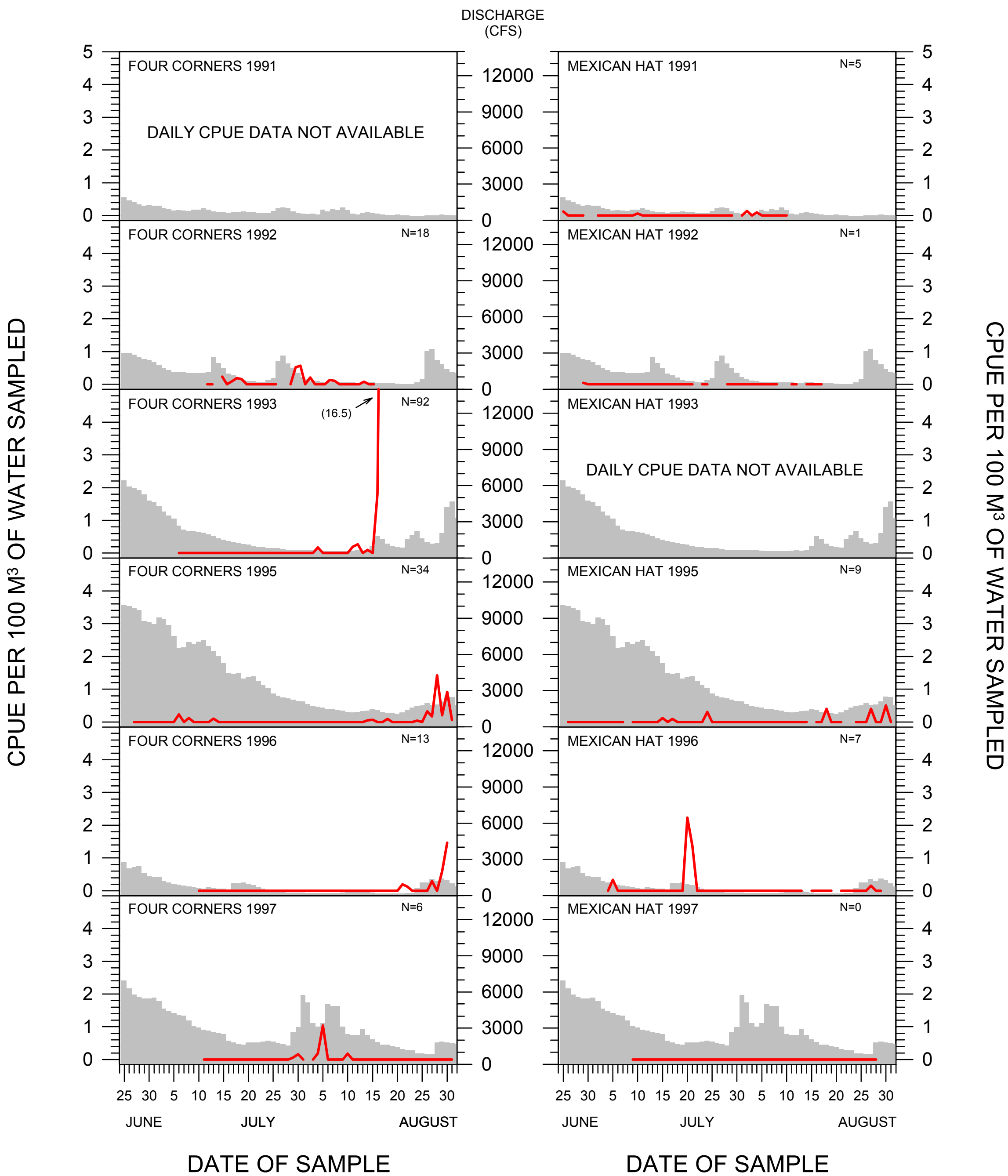

Figure 22. Fathead minnow CPUE at Four Corners and Mexican Hat from 1991-1993 and 1995-1997. Bar graph in background is discharge, while line graph in foreground is CPUE.

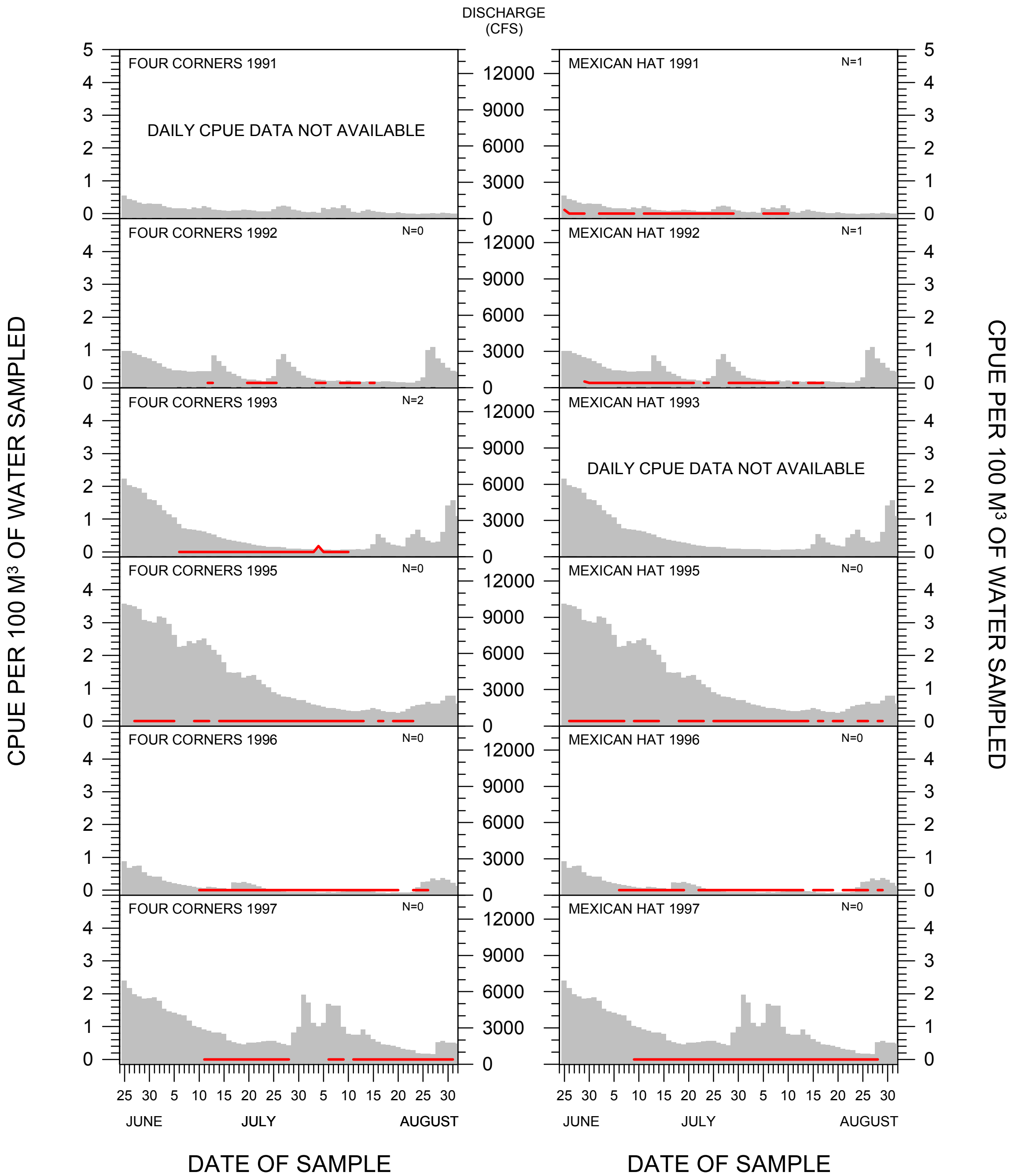

Figure 23. Fathead minnow CPUE (rainstorm events removed) at Four Corners and Mexican Hat from 1991-1993 and 1995-1997. Bar graph in background is discharge, while line graph in foreground is CPUE.

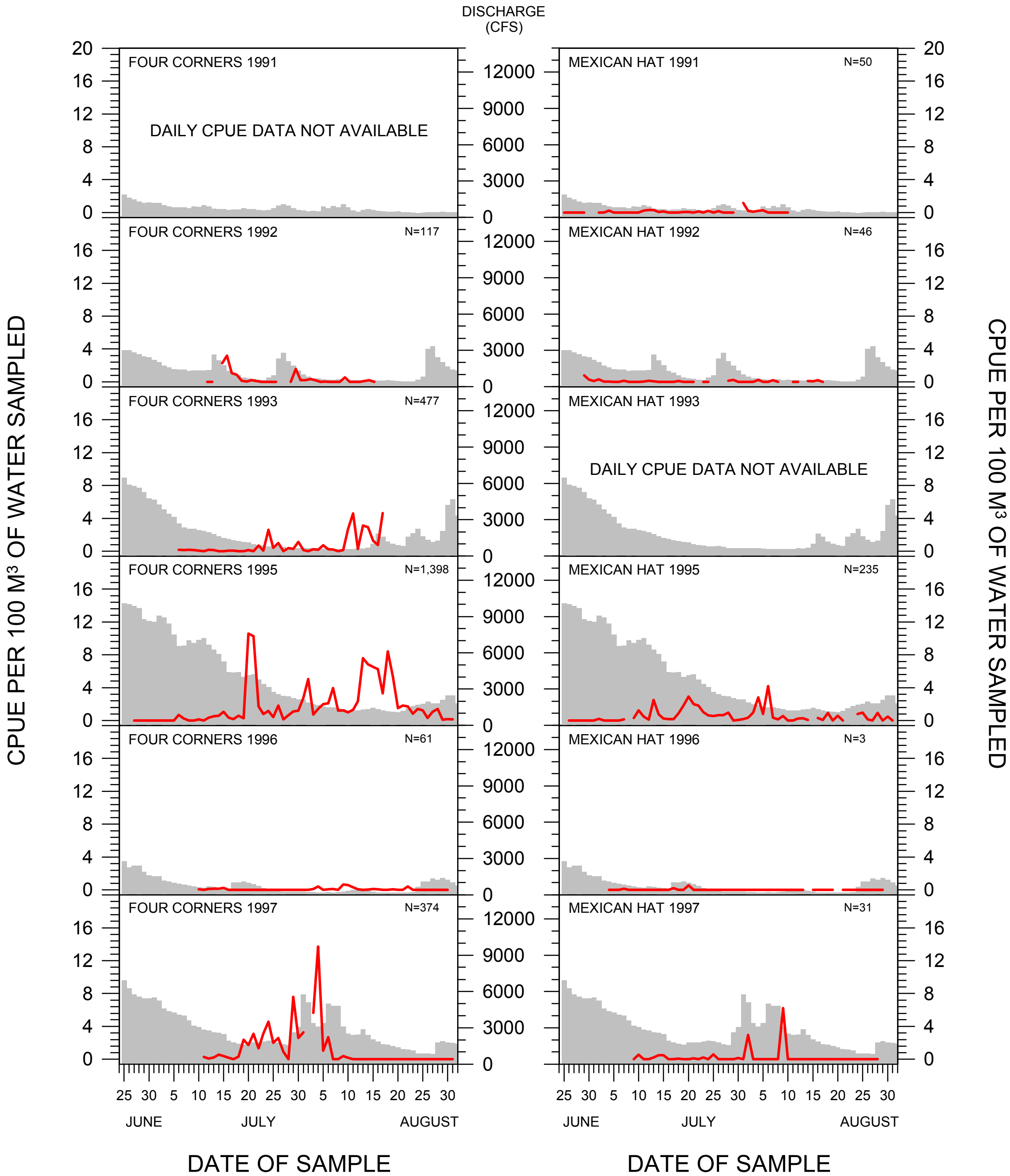

Figure 24. Speckled dace CPUE at Four Corners and Mexican Hat from 1991-1993 and 1995-1997. Bar graph in background is discharge, while line graph in foreground is CPUE.

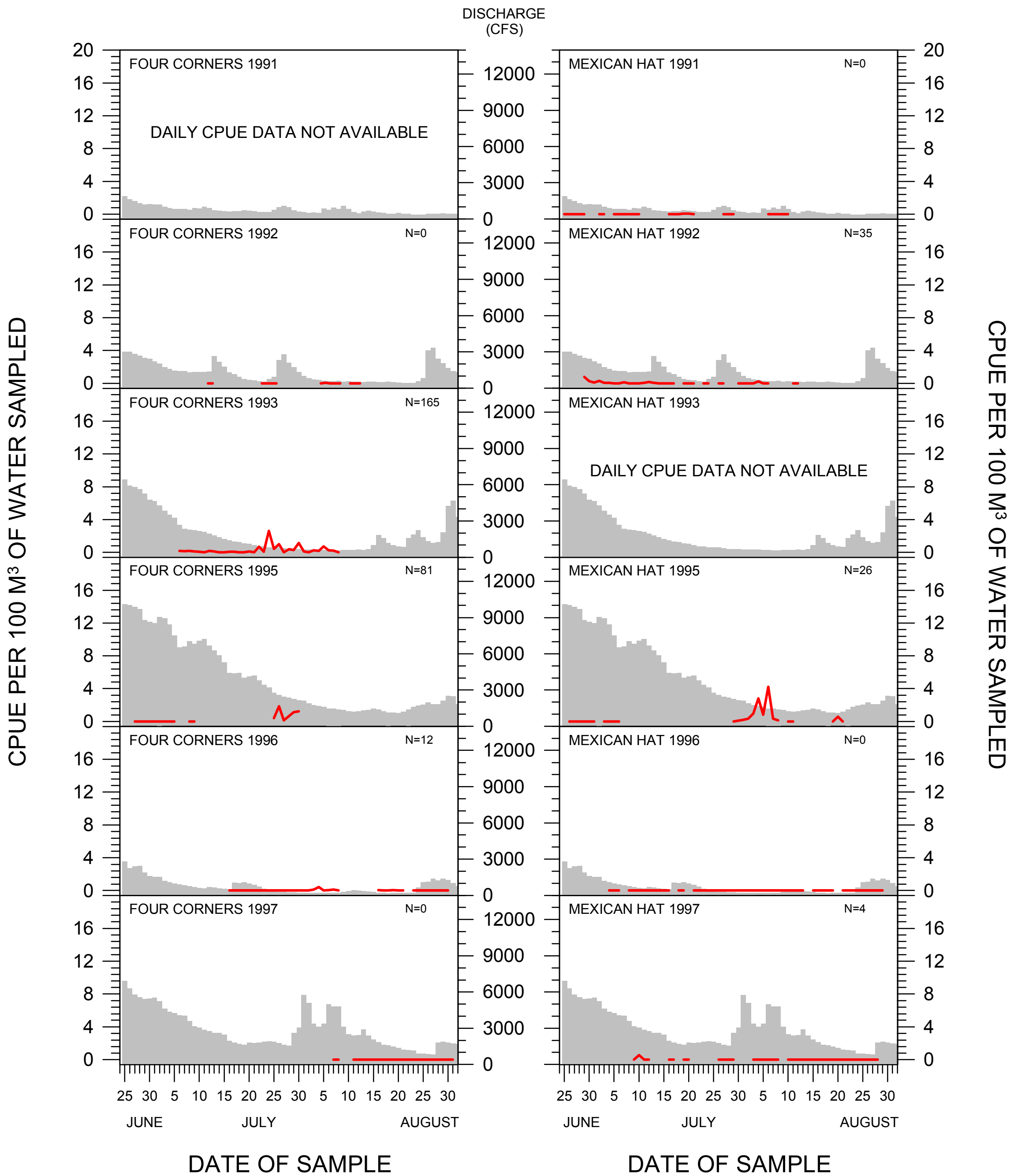

Figure 25. Speckled dace CPUE (rainstorm events removed) at Four Corners and Mexican Hat from 1991-1993 and 1995-1997. Bar graph in background is discharge, while line graph in foreground is CPUE.

events that contributed large amounts of debris and silt into the river. Low-flow conditions in 1996 apparently resulted in the collection of far fewer speckled dace than 1995. Speckled dace again were collected in moderate numbers in 1997 when summer flows were elevated. The largest number of drifting speckled dace, at both sampling sites, were taken after increases in flow. However, the size of the rain event was not correlated with the abundance of fish collected.

Flannelmouth sucker was taken during the three minor rainstorms in 1991 that affected flow at both sites during early July and early August (Figure 26). Flannelmouth sucker collected at Mexican Hat, while fewer than taken at Four Corners, was captured during minor increases in flow. Two rainstorms in July of 1992 coincided with the capture of large numbers (95.9%) of drifting flannelmouth sucker at Four Corners; few individuals were collected at Mexican Hat in 1992. Periods with no rain were rare and produced very few drifting individuals (Figure 27). Water levels in 1993 were high during the onset of sampling at Mexican Hat and most flannelmouth sucker taken during that year was collected from 29 June until 6 July. Individuals collected at Four Corners in 1993 were taken almost exclusively during periods of no rain (97.4%). While this pattern approximated that observed for speckled dace in the same year, flannelmouth did not spawn during the August 1993 summer rain events. Sampling in 1995 for flannelmouth sucker resulted in the capture of many individuals from late June until early July during high runoff. Almost no flannelmouth sucker was collected in 1996 or 1997 from either Four Corners or Mexican Hat; the few individuals captured were taken exclusively during increases in flow.

The numbers of bluehead sucker collected across sites and years mirrored the pattern observed for speckled dace both for rain (Figure 28) and non-rain periods (Figure 29). Neither collection locality produced many bluehead sucker in 1991, 1992, 1993, or 1996. While bluehead sucker apparently did not spawn much during the summers of 1991 and 1992, flannelmouth sucker catch rates were moderate to high during this same time. Moderate numbers of larval bluehead were drifting during non-rain periods in 1993 at Four Corners (70.4%) with the remainder arriving after early August rains. There was virtually no summer spawning by either species during the dry water year of 1996. The large collections of bluehead sucker in 1995 and 1997 were associated with rainstorms that were described by field personnel as resulting in reddish water and large amounts of instream debris. Summer spawning was documented for both species and at both sites in 1995 with larval bluehead sucker being collected later than flannelmouth sucker. In 1997, larval bluehead sucker were relatively abundant while flannelmouth sucker were relatively scarce (at both sites). All bluehead sucker at Mexican Hat and 99.7% at Four Corners were drifting during rain events.

Channel catfish were primarily collected following late summer rainstorms (Figure 30). Years with low-flow produced relatively high numbers of drifting individual channel catfish as compared to native species. The dates of collection of channel catfish in 1995 were notably later than observed for other years. This may have been due to cooler water temperatures that resulted from the large volume and long duration spring runoff. The single largest collection of drifting channel catfish occurred at Mexican Hat in 1997 during an extremely large rainstorm event. Only one of the 851 specimens collected during 1997 was taken during a non-rain period (Figure 31).

Back-calculation of Colorado pikeminnow based on larval and YOY specimens

A total of 47 YOY Colorado pikeminnow was collected in the San Juan River during the tenure of the research programs conducted between 1987-1996 (Table 6). The disposition of 12 of those individuals, all collected in September 1987 in the Utah portion of the study area, is unknown while one individual (collected on 9 September 1990) was released. The remaining 34 specimens have been curated in the Division of Fishes, Museum of Southwestern Biology at the University of New Mexico and were used to back-calculate spawning dates of Colorado pikeminnow. Back-calculated spawning dates were plotted on hydrographs (Four Corners gauging station) from the appropriate water year (Figures 32 and 33).

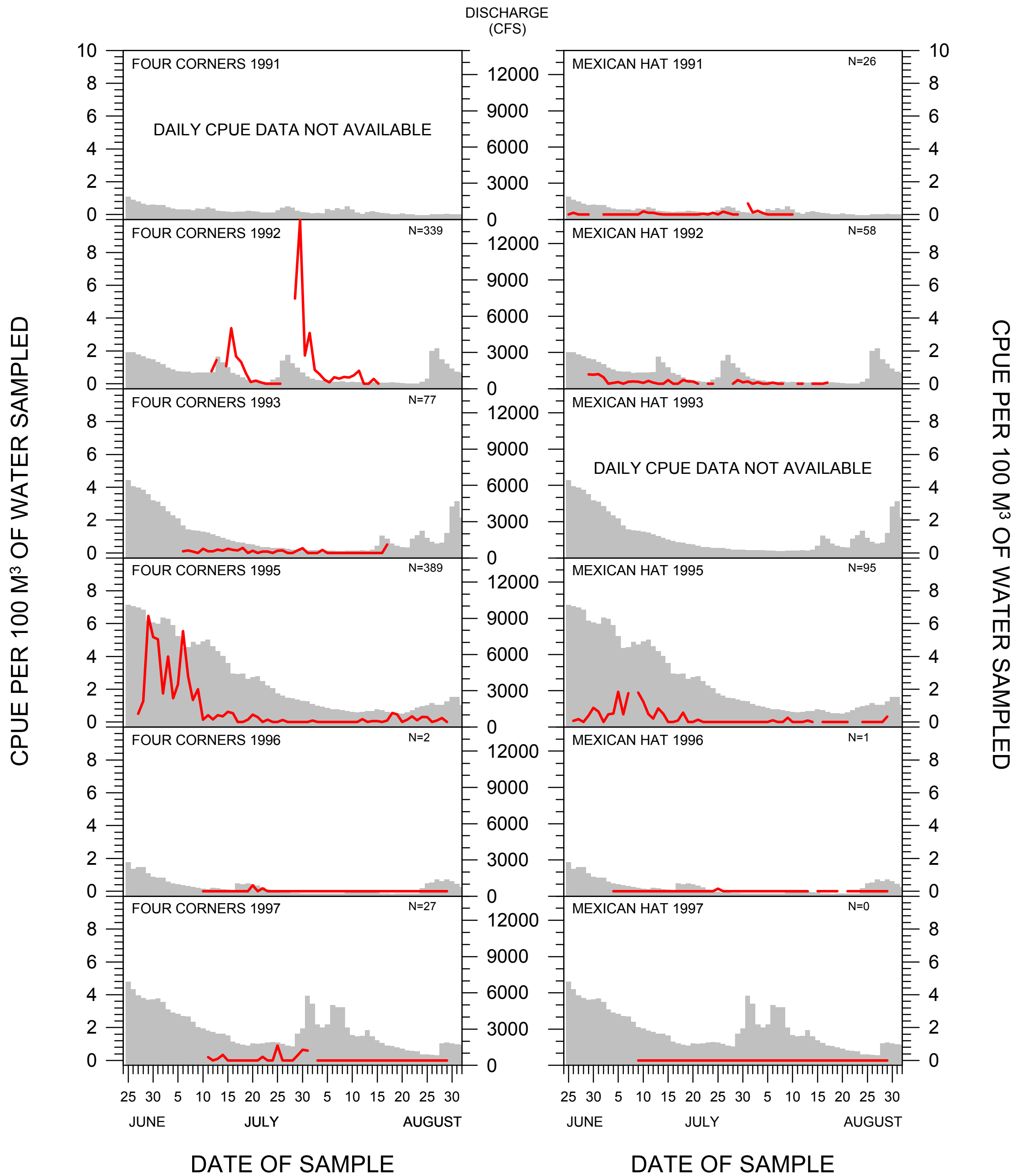

Figure 26. Flannelmouth sucker CPUE at Four Corners and Mexican Hat from 1991-1993 and 1995-1997. Bar graph in background is discharge, while line graph in foreground is CPUE.

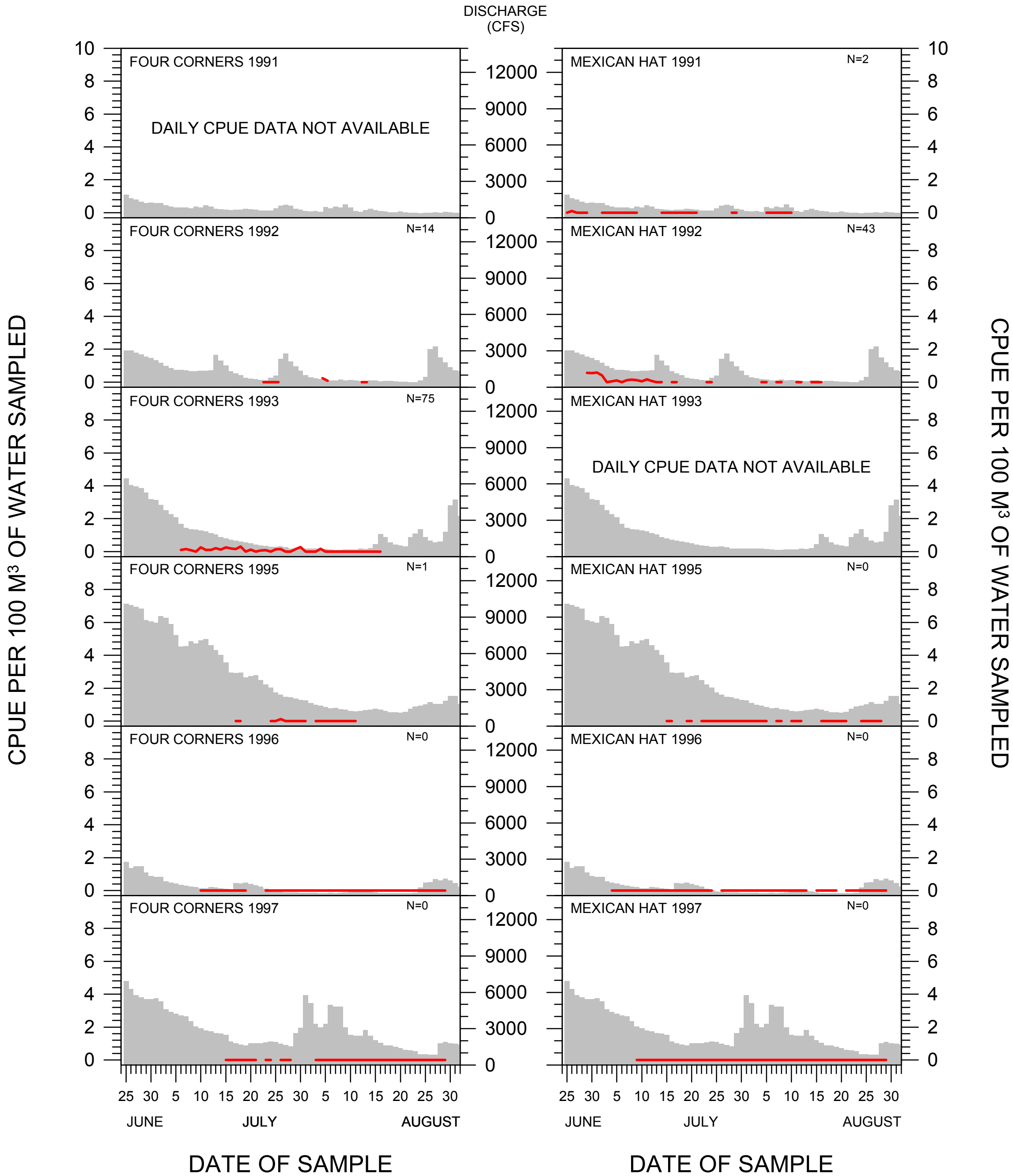

Figure 27. Flannelmouth sucker CPUE (rainstorm events removed) at Four Corners and Mexican Hat from 1991-1993 and 1995-1997. Bar graph in background is discharge, while line graph in foreground is CPUE.

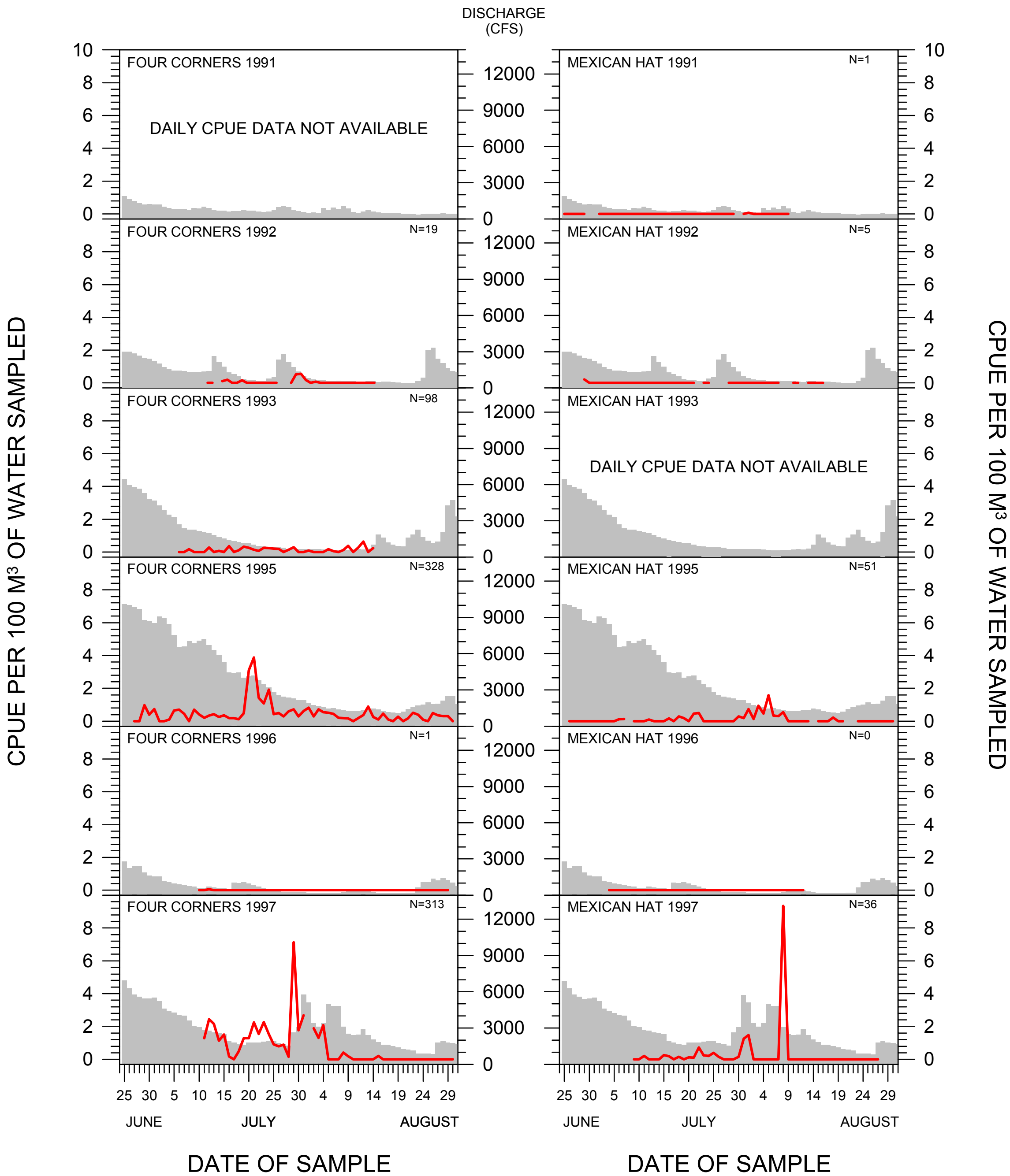

Figure 28. Bluehead sucker CPUE at Four Corners and Mexican Hat from 1991-1993 and 1995-1997. Bar graph in background is discharge, while line graph in foreground is CPUE.

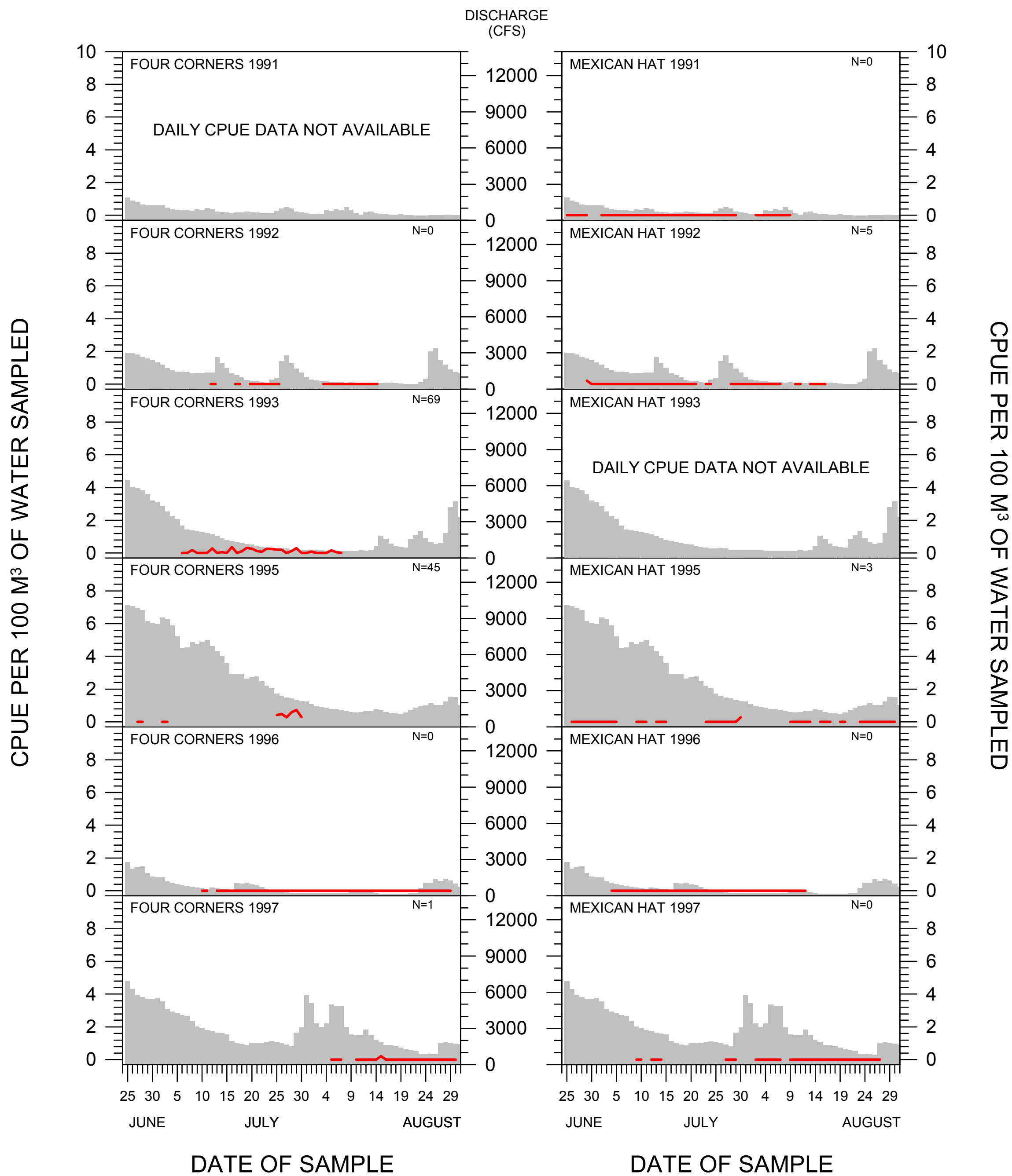

Figure 29. Bluehead sucker CPUE (rainstorm events removed) at Four Corners and Mexican Hat from 1991-1993 and 1995-1997. Bar graph in background is discharge, while line graph in foreground is CPUE.

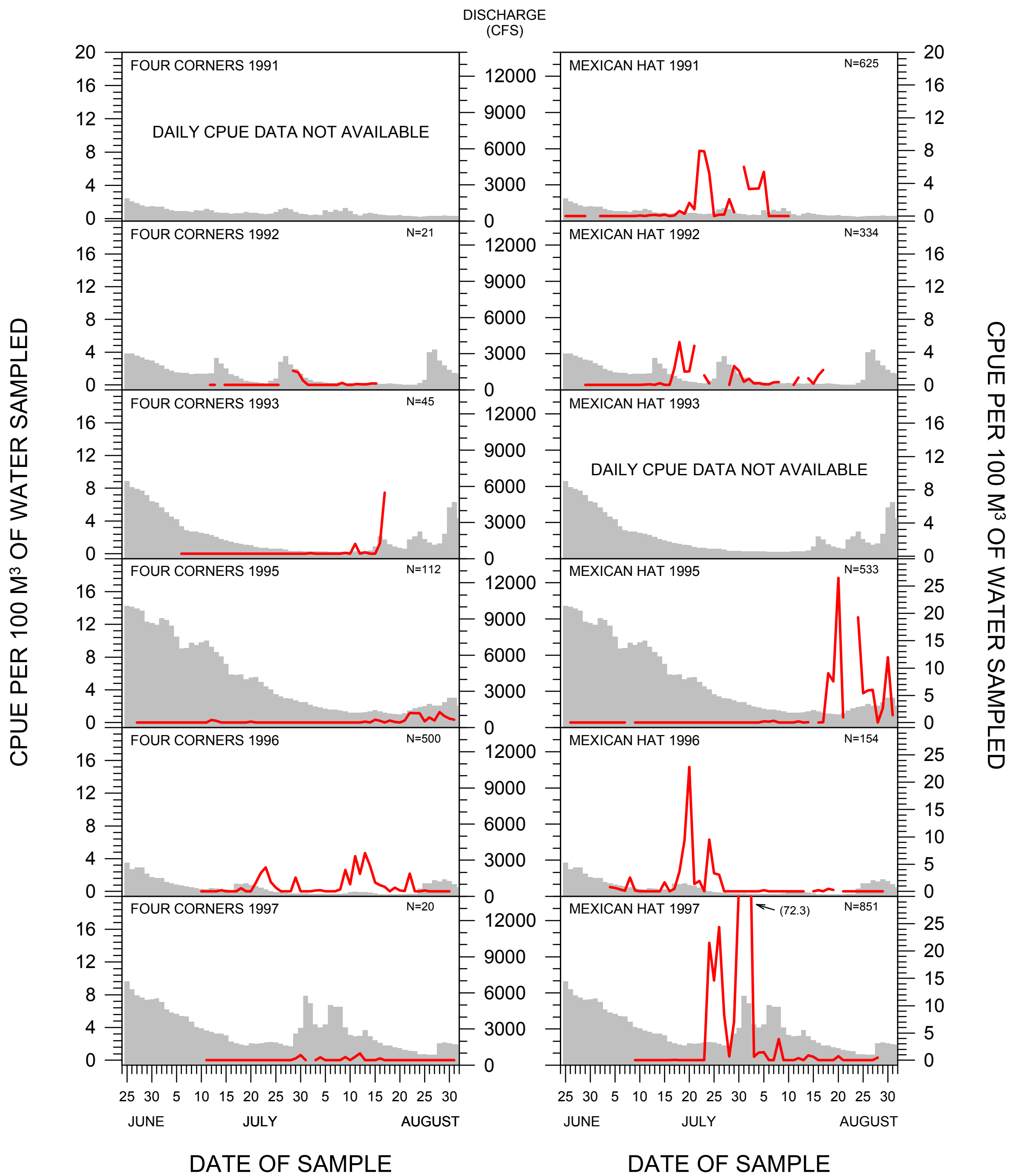

Figure 30. Channel catfish CPUE at Four Corners and Mexican Hat from 1991-1993 and 1995-1997. Bar graph in background is discharge, while line graph in foreground is CPUE.

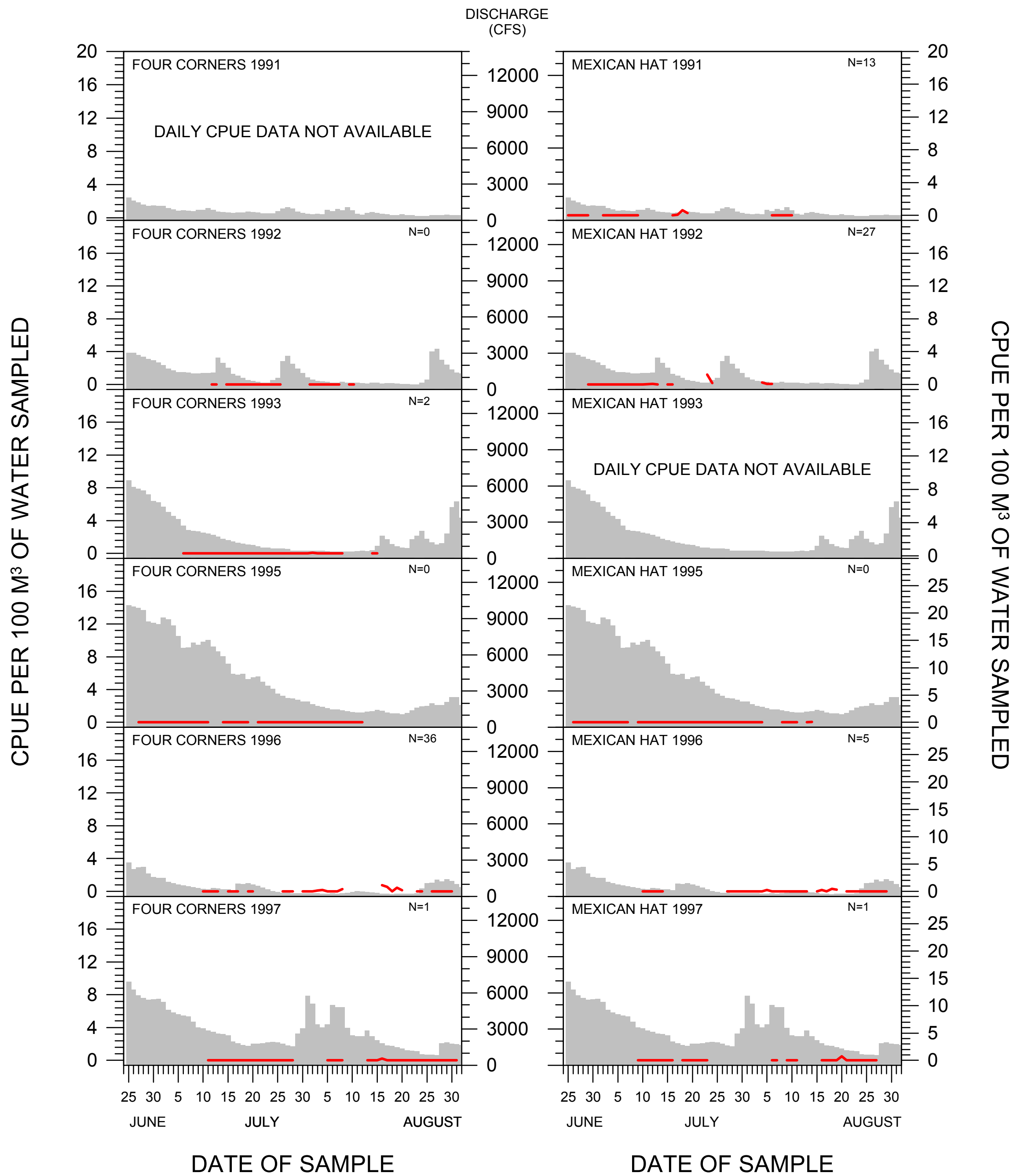

Figure 31. Channel catfish CPUE (rainstorm events removed) at Four Corners and Mexican Hat from 1991-1993 and 1995-1997. Bar graph in background is discharge, while line graph in foreground is CPUE.

Table 6. Summary of larval and YOY Colorado pikeminnow collected in the San Juan River 1987-1996[1] and back-calculated dates of spawning.

Field Number	MSB Catalog Number	Number specim.	Total Length	Date Collected	Date Spawned	River Mile	Sampling Method [2]
Z9084	9084	3	29.7	09 Sep 87	10 Jul 87	94.5	larval seining
"	"	-	27.4	09 Sep 87	16 Jul 87	94.5	larval seining
"	"	-	27.2	09 Sep 87	17 Jul 87	94.5	larval seining
deposition unknown	———	1	32	09 Sep 87	not calculated	101.7	larval seining
deposition unknown	———	2	27-28	09 Sep 87	not calculated	99.5	larval seining
Z8005	8005	1	17.2	13 Sep 87	14 Aug 87	ca. 34	larval seining
deposition unknown	———	2	26-29	20 Sep 87	not calculated	14.3	larval seining
deposition unknown	———	2	26-27	24 Sep 87	not calculated	9.4	larval seining
deposition unknown	———	4	26-27	24 Sep 87	not calculated	9.4	larval seining
deposition unknown	———	1	-	26 Sep 87	not calculated	6.0	larval seining
DLP-398	6264	1	28.0	10 Oct 87	14 Aug 87	126.4	larval seining
DLP-404	6265	1	38.4	11 Oct 87	17 Jul 87	122.9	larval seining
Z6609	6609	1	19.7	21 Aug 88	19 Jul 88	11.5	larval seining
released	———	1	34	9 Sep 90	not calculated	8.3	UT larval seining
Z11778	11778	1	23.3	22 Sep 92	09 Aug 92	-6.0	BR larval seining
MH72693-2	18098	1	9.2	26 Jul 93	08 Jul 93	53.0	drift netting
MH72793-2	18099	1	9.2	27 Jul 93	09 Jul 93	53.0	drift netting
KL93-012	15119	1	21.6	30 Aug 93	24 Jul 93	2.9	BR larval seining
KL93-018	15314	1	24.0	31 Aug 93	16 Jul 93	-0.4	BR larval seining
KL93-032	15234	1	19.1	01 Sep 93	31 Jul 93	1.8	BR larval seining
KL93-034	15264	1	32.4	01 Sep 93	24 Jun 93	1.2	BR larval seining
KL93-050	15159	1	18.4	02 Sep 93	02 Aug 93	-0.2	BR larval seining
KL93-053	15303	2	19.2	02 Sep 93	01 Aug 93	-0.1	BR larval seining
"	"	-	20.4	02 Sep 93	30 Jul 93	-0.1	BR larval seining
KL93B-023	15416	1	30.6	10 Oct 93	07 Aug 93	0.0	BR larval seining
KL93B-041	15501	1	30.1	12 Oct 93	10 Aug 93	3.0	BR larval seining
KL93B-045	15447	2	29.4	12 Oct 93	12 Aug 93	1.0	BR larval seining
		-	36.9	12 Oct 93	23 Jul 93	1.0	BR larval seining
SJLV94-3093	23604	1	14.0	04 Aug 94	08 Jul 94	122.6	UT larval seining
SJNB94-022A	23760	1	17.6	12 Aug 94	13 Jul 94	25.2	UT larval seining
SJNB94-065B	23974	2	18.3	13 Aug 94	13 Jul 94	9.8	UT larval seining
"	"	-	16.0	13 Aug 94	15 Jul 94	9.8	UT larval seining
SJNH94-3075	24495	1	25.9	24 Sep 94	04 Aug 94	8.0	UT larval seining
JPS95-205	26187	1	9.2	02 Aug 95	15 Jul 95	53.0	drift netting
JPS95-207	26191	1	9.0	03 Aug 95	17 Jul 95	53.0	drift netting
SJNB95-075B	29911	1	14.2	14 Aug 95	17 Jul 95	23.8	UT larval seining
SJNB95-084A	29912	1	14.3	15 Aug 95	18 Jul 95	22.3	UT larval seining
SJNB95-085B	29913	1	13.5	15 Aug 95	19 Jul 95	22.2	UT larval seining
SJNB95-092A	29914	1	15.1	15 Aug 95	18 Jul 95	21.0	UT larval seining
SJNB95-096B	29915	1	11.0	15 Aug 95	23 Jul 95	12.8	UT larval seining
WHB96-037	29717	1	8.6	02 Aug 96	18 Jul 96	128.0	drift netting

TOTAL
47 (includes all YOY and larval Colorado pikeminnow; i.e., all fish < Age 1)
34 (number of Colorado pikeminnow available for back-calculating spawning dates)

[1] This table includes only larval or YOY (=Age 0) Colorado pikeminnow captures.

[2]
larval seining - (n=7) larval fish seining conducted between 1987-1990 - this total does not include the 12 missing and 1 released specimen
BR larval seining - (n=12) larval fish seining in the vicinity of the San Juan River-Lake Powell confluence
drift netting - (n=5) annual (1991-1996) drift net sampling of larval fish drift
UT larval seining - (n=10) larval fish seining conducted between 1991-1996

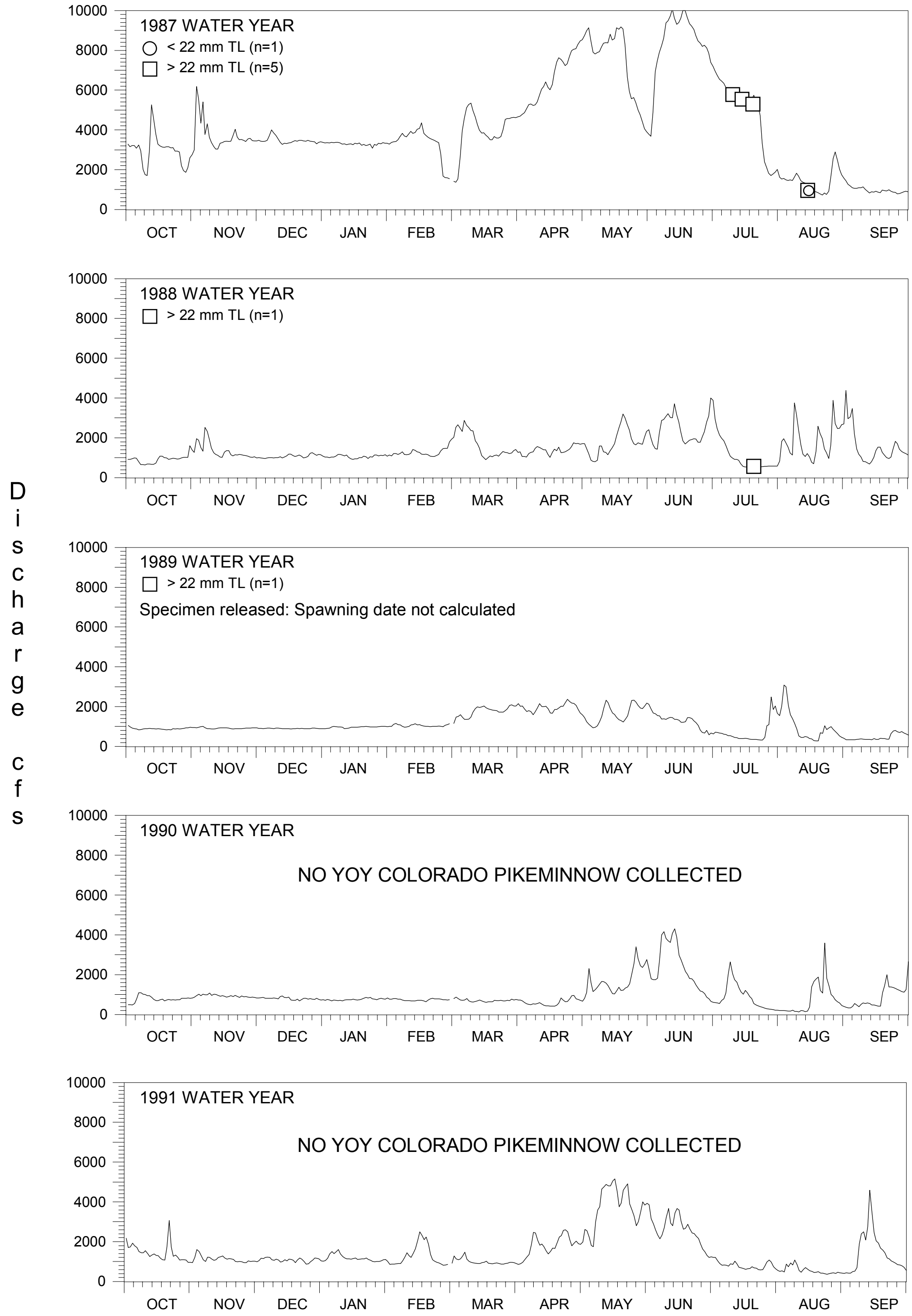

Figure 32. Back-calculated dates of spawning of Colorado pikeminnow based on YOY specimens collected in the San Juan River, 1987-1991. Hollow dots indicate individuals < 22 mm TL; solid dots indicate specimens (< 22 mm TL) collected in drift-nets; squares indicate specimens > 22 mm TL. Symbols may represent multiple individuals.

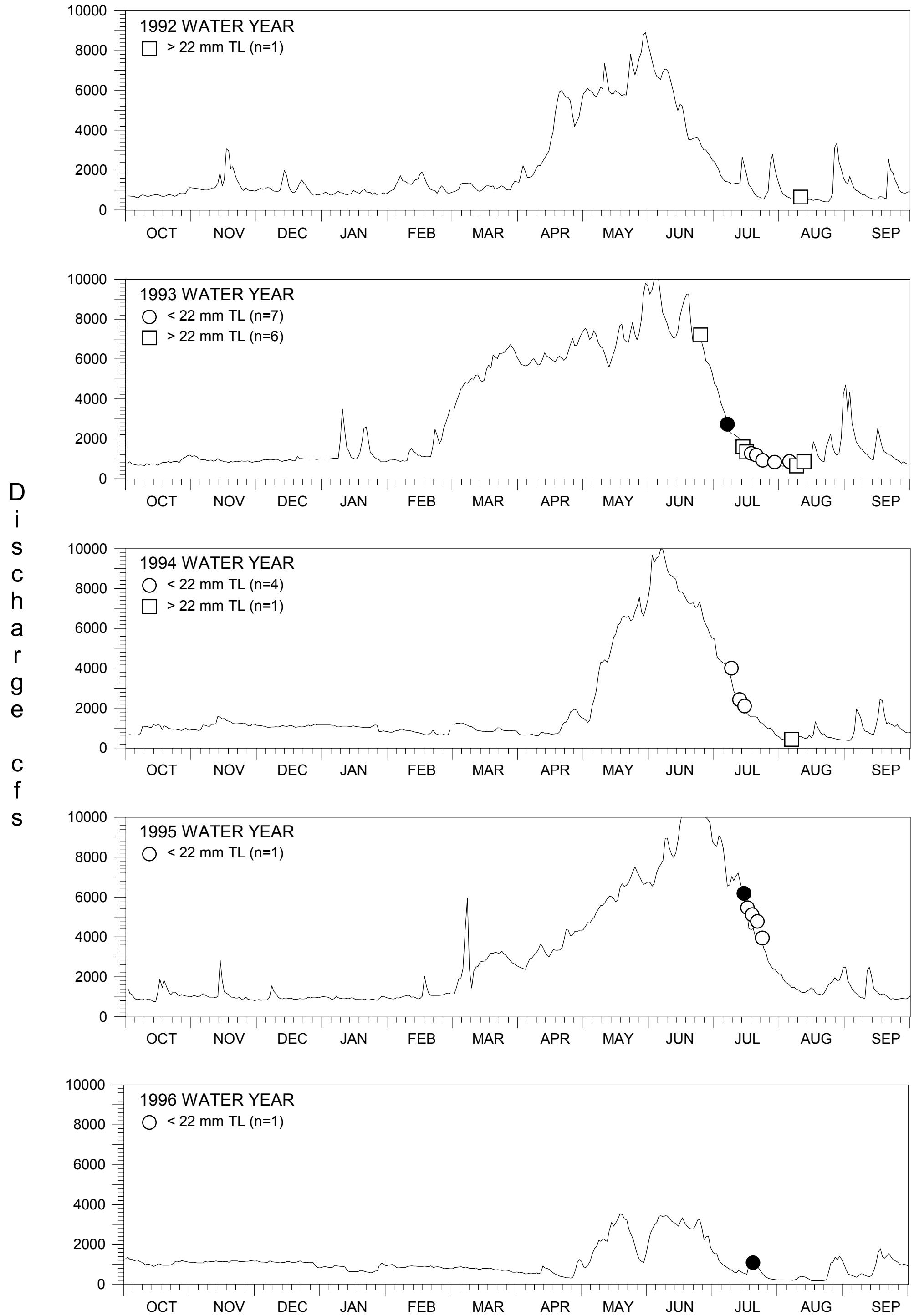

Figure 33. Back-calculated dates of spawning of Colorado pikeminnow based on YOY specimens collected in the San Juan River, 1992-1996. Hollow dots indicate individuals < 22 mm TL; solid dots indicate specimens (< 22 mm TL) collected in drift-nets; squares indicate specimens > 22 mm TL. Symbols may represent multiple individuals. No wild YOY Colorado pikeminnow were captured in 1997.

Nesler et al. (1988) provided a predictive equation for estimating post-hatching ages (in days) of Colorado pikeminnow <22.0 mm TL ($A= -76.7105 + 14.4949 L - 1.0555L^2 + 0.0221L^3$) and a separate formula for individuals 22.0-47.0 mm TL ($A= -26.6421 + 2.7798L$). Date of spawning was subsequently determined by adding five days (estimated incubation time for eggs at water temperatures of 20-22°C) to post-hatching ages. The potential for error in determination of post-hatching age and spawning dates increased with increasing size of YOY. Therefore, the most accurate estimates of spawning dates were deemed to be generated from the smallest (=youngest) Colorado pikeminnow specimens.

During the 1987-1989 study, 18 YOY Colorado pikeminnow were collected during 1987, one individual was taken in 1988, and none were taken in 1989. Although the three-year survey had ended and the seven-year research program had not yet begun, there was a cursory sampling effort for YOY fishes in 1990. The 1990 foray produced a single YOY Colorado pikeminnow (34 mm TL) on 9 September 1990 at RM 8.3; this individual was released and was not included in Figure 32.

Three research projects in the seven year research program, which began in 1991, concentrated efforts on the capture of YOY Colorado pikeminnow. Drift-net sampling provided information on the timing and duration of spawning in addition to quantifying reproductive success of selected members of the fish community. Larval fish sampling (identified in Table 6 as UT larval seining) involved extensive series of collections from low-velocity habitats throughout New Mexico and Utah and provided information on post-drifting YOY fishes. The Utah larval seining effort was supplemented by personnel from the Bureau of Reclamation (BR seining) who sampled primarily in the lower 20 miles of the San Juan River. Most of the BR sampling was in the immediate vicinity of the San Juan River-Lake Powell confluence that changed location annually depending upon the elevation of Lake Powell. The BR larval seining efforts were autonomous until 1995 when merged with Utah larval seining efforts.

Larval seining and drift-netting in 1993, 1994, and 1995 yielded 25 of the 27 YOY Colorado pikeminnow collected during the seven year research program. The other two YOY Colorado pikeminnow were taken (one each) in 1992 and 1996. With the exception of 1992, water years with the greatest discharge (1992-1995) yielded the largest number of YOY Colorado pikeminnow. In addition to the 27 YOY Colorado pikeminnow collected between 1991-1996, there were two Age 1 Colorado pikeminnow taken (and released) in 1994. Those two individuals (49, 59 mm TL) were collected at RM 11.6 on 7 April 1994. They are not included in Table 6 as it references only Age 0 (larval and YOY) Colorado pikeminnow.

The back-calculated date of spawning for the one YOY Colorado pikeminnow collected in 1992 was 9 August 1992. This was one of the latest back-calculated spawning dates and, if true, would indicate that in 1992 Colorado pikeminnow spawned considerably after spring runoff had terminated and between summer rainstorm events. While this date is not outside of the range of spawning dates predicted from YOY Colorado pikeminnow collected during the seven year research program, the single individual and its relatively large size (23.3 mm TL) reduce the level of confidence in this predicted spawning date.

Two of the 13 YOY Colorado pikeminnow collected in 1993 were taken in drift-nets. These individuals were the same length (9.2 mm TL) and were taken on consecutive days in late July (26-27). From these two individuals, the date of spawning was determined to be about 8-9 July 1995. Water temperature during this time averaged 18°C (daily range=16.0°C to 20.5°C). The back-calculated dates of spawning, as ascertained from 10 of the 11 seined YOY Colorado pikeminnow, ranged between 16 July-12 August 1993. The date of spawning calculated for a 32.4 mm TL individual (24 June 1993) represents an outlying data point. Colorado pikeminnow spawning in 1993 appears to have occurred as discharge in the San Juan River was declining.

Four of the five YOY Colorado pikeminnow captured in 1994 were <22 mm TL (14.0-18.3 mm TL). The hypothesized spawning dates, as determined from these four individuals, was between 8-15 July 1994 and occurred on the descending limb of the hydrograph. Conversely, if Colorado pikeminnow had spawned on 4 August 1994, as predicted from the 25.9 mm TL individual, it would have occurred after spring runoff and during a period of relatively low discharge. Additional support for the July 1993-1994 predicted spawning dates was supplied by Miller (1994, 1995) who, during mid-July of both years, tracked radio-tagged adult Colorado pikeminnow to the presumed spawning areas.

Two of the seven YOY Colorado pikeminnow collected in 1995 were taken in drift-nets at the Mexican Hat study site. The similar size and developmental stage of these two individuals, in combination with the fact that the two fish were collected within 12 hours of each other, strongly suggest that they were cohorts from a spawning event. The other five YOY Colorado pikeminnow collected in 1995 (11.0-15.1 mm TL) were taken on 14-15 August 1995. Back-calculated spawning dates, as determined from the seven 1995 YOY Colorado pikeminnow, were between 15-23 July 1995. This was the most restricted hypothesized spawning period generated from the formula provided by Nesler et al. (1988). If these predicted dates are accurate, than spawning would have occurred about one month after peak flow (19 June 1995; 12,100 cfs) and during the decreasing spring runoff discharge. Water temperature for the hypothesized date of spawning for the two drifting larval fishes averaged 18°C (daily range=16.5°C to 20.5°C).

A single YOY Colorado pikeminnow was collected in 1996. The specimen was a 8.6 mm TL yolked-mesolarvae taken on 2 August 1996 in a drift-net at the Mixer sampling locality (RM 128.0). This individual represents the only larval Colorado pikeminnow collected during drift-net sampling at the Mixer. The 1996 back-calculated spawning date for Colorado pikeminnow (18 July 1996) was for the same period predicted in 1995 despite considerable difference in spring peak discharge (1995 - 12,100 cfs; 1996 - 3,450 cfs) and total annual discharge (1995 water year - 1,065,148 acre feet; 1996 water year - 411,297 acre feet). Water temperature during the proposed spawning period averaged about 18.5°C (daily range=16.0°C to 22.5°C).

DISCUSSION

During this investigation, discharge in the San Juan River varied between the extremes of the high and sustained flows that occurred in 1993 to the near drought conditions of 1996. The duration and magnitude of flow, that resulted from manipulation of Navajo Dam, was vastly different on given days between years. There was also considerable variability in the timing, frequency, amplitude, and magnitude of summer rainstorm events that occurred during the seven-year study period.

Catch-per-unit-effort for the six most abundant species (red shiner, fathead minnow, speckled dace, flannelmouth sucker, bluehead sucker, and channel catfish) taken during the passive drift-netting study revealed a positive relationship between the number of drifting larvae that were collected per unit of water sampled and occurrence of summer rainstorms. However, the magnitude, duration, or number of rain events during a year did not appear to strongly relate to larval fish density fluctuations within or between years. Flow in the river increased immediately after rainstorms and while increases were often quite minor, they usually resulted in the deposition of substantial amounts of sediment and debris into the river. These climatic events appeared to be responsible for increased catch rates of larval fishes in drift-nets. Even minor rainstorm events, which did not yield obvious or marked increases in flow, resulted in elevated catch rates of drifting fishes. Increased amounts of sediments brought into the river by rainstorms reduced water visibility to near zero. Low water visibility and high levels of instream debris would usually continue several days following the rainstorm. The majority of drifting fishes were collected during this latter period. Both the amount of suspended instream debris and number of drifting fishes captured diminished as water levels declined and water clarity improved.

Studies of mesolarval and metalarval native fishes in other portions of the Colorado River Basin suggest their movements between near-shore habitats are not passive (Robinson et al., 1998). Near-shore habitats may be preferred by drifting larval fish as these areas are characterized by low water velocities (i.e., decreased metabolic cost), increased food availability and water temperature, presence of more elaborate/suitable cover, and decreased predator contact. Historically, downstream movement of larvae from tributaries would have resulted in transport of fish through the river system and into the mainstem Colorado River during the period most likely to ensure their continued growth and survival (Robinson et al., 1998). For native fishes, the altered and degraded nature of the mainstem Colorado River may now mean that their inherent behavior of drifting is often detrimental.

The tendency of larval fish in the San Juan River to drift during summer rainstorms certainly results in a proportion of the reproductive effort being carried downstream into the unsuitable habitats of Lake Powell. This displacement would likely be most dramatic in the extensive downstream canyon-bound reaches (i.e., about the final 100 km of the river before it emptied into Lake Powell). The presence of numerous post-larval Colorado pikeminnow several hundred km downstream of hypothesized spawning areas in the Green and Yampa rivers is indicative of the distance of displacement (Tyus, 1986; Tyus et al., 1987; Tyus and Haines, 1991). This pattern has also been documented in the San Juan River through the collection of larval fishes near the inflow to Lake Powell with most spawning adults having been collected 100 to 250 km upstream (Platania et al., 1991; Ryden and Ahlm, 1996). The lost of larval fishes and the impact on their population dynamics have not been quantified but studies designed to address these questions are underway. The recovery of native San Juan River fishes is integrally linked to understanding the fate of Colorado pikeminnow propagules.

Prior to construction of Glen Canyon Dam, a portion of San Juan River drifting fishes would have dispersed into the mainstem Colorado River. It is probable that some displaced individuals would have returned to the river reaches from which they were spawned. This behavior, in the form of upstream movement of subadult (30-50 cm TL) Colorado pikeminnow, was reported by Tyus (1991) and deemed a principal mechanism for re-populating upper river reaches. In addition, adult Colorado pikeminnow have been tracked using radio-telemetry, making spawning migrations of several hundred km to specific sites and passing reaches apparently suitable for spawning. Olfactory cues have been hypothesized as the mechanism responsible for this homing behavior (Tyus, 1985, 1990). This latter movement pattern has also been observed in Colorado pikeminnow in the San Juan River (Ryden and Alhm, 1996) although many of the individuals moved less than 50 km to putative spawning areas. Instream barriers and reservoirs that block upstream movement of fishes may be preventing adult Colorado pikeminnow from reaching preferred spawning areas and sub-adult and juvenile fish from being able to re-populate upstream reaches (Tyus, 1985).

The reasons that larval fishes were more likely to drift during and following rain events are not fully understood. There may be benefits to larval fish movement during events that transport large amounts of debris and suspended sediment into the river. These conditions, which occur even during small rainstorms, may provide instream cover that protect small fishes from predation. Laboratory experiments demonstrated that larval razorback sucker (*Xyrauchen texanus*) are extremely susceptible to predation, by both native Colorado pikeminnow and nonnative green sunfish (*Lepomis cyanellus*), in relatively clear water but are significantly less susceptible to predation by either species in turbid water (Johnson and Hines, 1998). Increased drift rate by larval San Juan River fishes during the altered physical river conditions induced by rainstorms may be a predator avoidance mechanism or simply be due to loss of orientation. It is also possible that larvae departed interstitial spaces as sediment settled out of suspension and into these protected areas (Bestgen et. al., 1998). Benefits attained by larval fish from these behavioral responses may, in part, explain the phenomena observed during the tenure of this study.

While consistent and reliable measures of turbidity were not available for the entire duration of this study, it appears that turbidity affected daily CPUE value for drifting fishes. Turbidity level in the San Juan River invariably increased regardless of whether the magnitude of the rainstorm was high or low. Preliminary data suggest that the presence, not level, of turbidity was more important in predicting fish density (e.g., highly turbid water did not result in higher densities of drifting larval fish than moderately turbid water). This may be because nearly all rain events, regardless of magnitude, resulted in increased instream turbidity and reduced water visibility especially when compared to the normally clear discharge from Navajo Reservoir.

Fluctuations in mean daily water temperature were generally minimal and did not seem to account for the daily variability in fish CPUE levels. However, overall larval density for nearly all of the species examined (except native suckers) appeared to peak in late July and early August when water temperatures in the San Juan River also typically peaked. Large rainstorms can result in moderate water temperature fluctuations but most changes were undetectable due to the small size of the events; the magnitude of the temperature change did not appear to greatly affect larval fish catch rates.

The ability to catch fish did not appear restricted to reproductive output. Under high flow conditions it was necessary to sample near shore habitats where water velocity and depth were both lower than in the main channel and therefore more manageable. This situation sometimes resulted in sampling of a smaller volume of water than during more normal flows. During high flows, the amount of instream debris and sediment in the river also was dramatically higher than during periods of low flow. This additional material would clog the openings of the collecting devices and result in the sampling of a lesser volume of water per unit time. Summer rainstorms, in addition to increasing flow, often transported substantial amounts of debris to the river. In contrast, stable flows (either low or high) yielded clear water, little debris, and efficient sampling. Despite the challenges caused by high flow, the majority of fishes were collected when conditions were at their least desirable point (i.e., large amounts of instream debris).

There were marked annual differences in the proportion of the catch comprised of drifting versus incidental fishes. These differences likely reflected the high annual variability of flow conditions. Only 57% of fish caught in 1993 were drift, while 87% were drift in both 1995 and 1996. Percent drift also varied somewhat predictably by species. Nearly all bluehead sucker and channel catfish caught were drifting larvae. Conversely, only about 66% of speckled dace and flannelmouth sucker and 50% of fathead minnow caught were classified as drift. Differences in percent drift by species almost certainly correspond to differences in life history strategies (e.g., length of drifting stage, rate of larval development, larval response to flow, susceptibility to displacement). Species-specific correlations between mean annual CPUE and flow regime were significant for speckled dace and channel catfish. Speckled dace were more numerous in drift-net samples during years when flows were consistently high than in years with lower flows. Correlation analyses illustrated this pattern at both sampling localities. Years when speckled dace were most abundant were characterized by high volume spring flows of cool water. Throughout the study period, drifting larval speckled dace were generally most abundant at the beginning of the sampling period when water temperatures were cool.

Years with consistently high flows (i.e., many days with discharge above 2,500 cfs or 5,000 cfs) were associated with mean annual catch rates of channel catfish that were lower than during low flow years. Conversely, years with consistently low flows (i.e., many days with discharge less than 500 cfs) were associated with larger numbers of drifting larval catfish than were high flow years. While high flow years were generally associated with smaller numbers of drifting channel catfish, years with very high flow (e.g., several days above 10,000 cfs) resulted in notably higher catch rates for this species. The strength of this correlation was primarily the result of data from 1997 when larval channel catfish density was higher than during any other year of the study. The majority of drifting 1997 channel catfish were taken immediately after the onset of a late July rainstorm that rapidly doubled flow to about 6,000 cfs. Large numbers of individuals were likely transported out of nursery habitats which resulted in elevated channel catfish catch rates.

The peak of flannelmouth sucker spawning in other southwestern systems generally occurs in late spring and early summer (Minckley, 1973; Lanigan and Berry, 1981; Tyus and Karp, 1990; Robinson et al., 1998; McKinney et al., 1999) and has been observed in March in Lower Colorado River tributaries (Weiss et al., 1998). Bluehead sucker usually spawn during early summer (Minckley, 1973; Maddux and Kepner, 1988; Tyus and Karp, 1990; Robinson, 1998). While spawning of native flannelmouth sucker and bluehead sucker appeared to occur earlier in the year than other species, no gradual decline of catch rates (over the summer sampling period) was observed. The collection of drifting larvae of both species at the onset of sampling (during some sampling years) indicated that spawning occurred in spring or early summer.

Summer spawning by flannelmouth sucker and bluehead sucker probably depends on environmental cues different from those that occur in spring. For example, water temperature is likely to be an important spawning catalyst in the spring, while increases in flow may be relatively more important for sucker reproduction during summer. The magnitude of summer spawning by suckers is certainly influenced by the level of spring spawning. Earlier and continual sampling (April-June) for Catostomid larvae is necessary to provide a more complete understanding of the reproductive and drift ecology of this taxon in the San Juan River.

The number of Colorado pikeminnow collected during the drift-netting phase of the San Juan River seven-year research program was small (n=5) especially when compared with similar studies in other portions of the Upper Colorado River Basin. While the low number of specimens precluded statistically meaningful comparisons and conclusions regarding correlation between reproductive success and discharge pattern, this study was able to document important information regarding location of Colorado pikeminnow spawning areas. Radio-telemetry work conducted in 1993 indicated the presence of two Colorado pikeminnow spawning bars in the Mixer reach of the San Juan River between RM 131.0-132.0. In 1996, the collection of an 8.6 mm TL yolked-mesolarvae Colorado pikeminnow (RM 128.0) verified the presence of an upstream spawning bar and provided additional validation for the observations provided by Miller (1995).

Colorado pikeminnow initiated reproduction at water temperatures ranging from 18.0°C to 18.5°C, nearly at the mid-point of the range observed for the species (Hamman 1981, Tyus 1990, Tyus and Haines 1991, Bestgen et al., 1998). Water temperature in the San Juan River had risen rapidly during the few weeks preceding the initiation of Colorado pikeminnow reproduction. This same pattern has been reported in other Upper Colorado River Basin pikeminnow studies (Tyus 1990, Tyus and Haines 1991). This rise in San Juan River water temperatures generally coincided with a relatively rapid decline in flow during summer.

The two larval Colorado pikeminnow collected at Mexican Hat in drift-nets in 1995 provided an additional suite of important information. The small size of the two individuals, identical developmental stage (both early yolked-mesolarvae), and similar time of collection suggested that the two fish originated from the same spawning bar. That these two individuals were collected within 12-hours of each other also suggested relatively synchronous drift of larvae from spawning beds. The most probable scenario to explain the similarities regarding the time of collection and developmental stage of these two individuals was that they originated from a spawning bar downstream of that first identified in 1993 by Miller (1995). The Mexican Hat sampling locality (location where these two individuals were collected) was about 78 river miles downstream of the Mixer spawning bar. The probability of sequential collections of drifting Colorado pikeminnow, in a 12-hour period, that originated from the same spawning location decreases considerably the farther one is removed from that putative site. In addition, the magnitude of Colorado pikeminnow spawning and drift from the Mixer spawning bar that would have had to have occurred to result in these two specimens being taken at Mexican Hat, would likely have resulted in the collection of drifting Colorado pikeminnow at the Four Corners site. This latter sampling locality was only 4-5 miles downstream of the Mixer spawning bar.

In addition to providing information on the location of spawning bars, timing of reproduction, and verification of reproduction by Colorado pikeminnow, data provided by the passive drift-netting study validated the low population density estimates of this species that have been suggested by other investigations. This study, in conjunction with YOY seining efforts, suggested that aspects related to the drift portion of this species life-history may be the principal reason for the current rarity of Colorado pikeminnow. Studies specifically designed to answer these questions are underway.

CONCLUSION/MANAGEMENT IMPLICATIONS

Objectives

The information acquired from the drift-netting segment of the seven-year research effort fulfilled the original study objectives and provided information necessary to complete specific tasks outlined in the long-range plan section of the San Juan River Recovery Implementation Program. Original study objectives, as listed in annual work plan documents, were:

1) determine the temporal distribution of San Juan River ichthyoplankton in relation to the hydrograph,

2) provide comparative analysis of the reproductive success of San Juan River fishes,

3) attempt to characterize downstream movement of ichthyoplankton,

4) attempt to validate presumed spawning period of Colorado pikeminnow.

1) The drift-netting study was able to provide considerable information on temporal aspects of spawning of most San Juan River fishes. The time during the sampling period that individual taxa were likely to drift was highly variable but generally occurred in late July and early August. This was also the time of the year when monsoonal moisture was most likely to result in rain events. The high variability in the temporal drift patterns of these species appeared to be due to their affinity to drift during rainstorms which occurred randomly throughout the study period.

Funding constraints on this work required that the sampling effort be concentrated during the putative period of spawning and drift (July-August) of Colorado pikeminnow. The lack of drift-net sampling in May or June precluded the possibility of assembling a complete temporal spawning dataset for the earliest reproducing fishes in the San Juan River (speckled dace, flannelmouth sucker, and bluehead sucker). Densities of drifting speckled dace and bluehead sucker generally peaked over a narrow period in late July and early August. Densities of flannelmouth sucker peaked in early to mid-July and its drifting larvae were nearly absent in August for all years. Red shiner and fathead minnow catch rates increased only in August after flows had dropped substantially (i.e., below 2,000 cfs) and water temperatures began to rise following spring runoff. However, the termination of the drift-net sampling effort at the end of August potentially excluded spawning periodicity information, especially in September, for these protracted spawners. A portion of the data necessary to provide a more complete temporal description of species-specific spawning periodicity could be gleaned from other research projects (secondary channel and larval fish sampling).

Correlating spawning periodicity with annual hydrographs proved undemonstrable (for several reasons) for most species. An important pattern that obscured the aforementioned correlation was the existence of a strong positive relationship between the occurrence of individual rain events and increased CPUE for all fishes. Increased drift of larval fish occurred both as flow escalated and as post-rain event flow receded. Large pulses of drifting fishes were collected during this period. Large and small rainstorms both resulted in an increase in drift rates of fishes.

The association between increased CPUE and rain events was extremely strong. However, this comparison was not analyzed statistically because of the large frequency of rain events that occurred annually (even if events were relatively minor and did not result in noticeable increases in flow) and because of the virtual absence of drifting fish during non-rain periods. Thus, correlation between these two variables (flow and CPUE) were generally inappropriate. Local climatic events were much more informative than the annual hydrograph for assessing catch rates of drifting fish.

2) The abundance of drifting larval fish was highest in 1995 when base flows reached their maximum. This trend was primarily driven by the large numbers of speckled dace collected at the upper site. Speckled dace was the most frequently collected drifting larval fish and peaked in abundance in 1993, 1994, 1995, and 1997. High base flow years generally resulted in the collection of more native (speckled dace, flannelmouth sucker, bluehead sucker) than nonnative (red shiner and channel catfish) individuals; the reverse was true in low base flow years. This trend was most apparent in 1996 when the lowest flows over the course of the study resulted in greatly reduced densities of speckled dace and the near absence of either native sucker species. The upper site produced more individuals of native than nonnative taxa than did the lower site during most years.

However, for many of the same reasons stated in the previous objective (number 1), it was not practical to provide detailed comparative analysis of the reproductive success of San Juan River fishes. The absence of drift-net sampling prior to July and after August limited attempts to assess reproductive success for species that spawned during those periods. The number of Colorado pikeminnow captured in drift-nets (n=5) proved to small, even when subjected to likelihood analysis (Bayesian approach), to determine annual variation in larval density. Increases in population levels of reproducing adult Colorado pikeminnow may be necessary before significant annual differences in larval pikeminnow density can be detected.

3) Qualitative characterization of the downstream movement (drift) could be assessed only for Colorado pikeminnow. Larval pikeminnow collected in drift samples in 1993 and 1995 provided information suggesting location of adult pikeminnow spawning areas. The small size of the individuals, identical developmental stage, and similar time of collection suggest synchronous drift of larvae from the same spawning bar. The most probable scenario to explain similarities regarding the comparable time of collection and developmental stage of individuals was that they originated downstream from the Mixer spawning bar first identified in 1993 (Miller 1994). In 1996, the collection of a mesolarval Colorado pikeminnow at RM 128 provided verification and additional validation of an upstream (Mixer) spawning bar.

Review of drift data, larval fish seining efforts, and river morphology suggest that downstream transport of drifting larval Colorado pikeminnow into unsuitable habitats was an important factor which lead to their decline in the San Juan River. Over 77% (n=27) of YOY Colorado pikeminnow taken in seine samples were captured in the lower-most 25 miles of the San Juan River and upper Lake Powell. Documentation of spawning upstream of RM 128 and RM 55 indicate that the larval stage of this species drift considerable distances before attaining the physical mobility and behavioral stimulus necessary to invade and occupy low-velocity habitats. Studies designed to provide a quantitative assessment of rates of drift and downstream displacement of larval fishes were begun in 1998 and continued in 1999.

4) The putative spawning period for Colorado pikeminnow, as determined from specimens taken both in drift-nets and seine collections, was generally during July as spring runoff receded and water temperatures increased. Mean daily water temperature during the back-calculated dates of spawning for drifting larval individuals was between 18.0°C and 18.5°C. In all cases, water temperatures had warmed at least 5.0°C in the previous few weeks before spawning occurred. Examination of Colorado pikeminnow larval fish capture data, annual hydrographs, water temperature information, and behavioral data on radio tagged adult pikeminnow strongly support the supposition of July spawning. The period of drift for larval Colorado pikeminnow was more restricted than that of spawning as all five drifting larvae were collected either during the last week of July or first week of August. The pattern of drifting pikeminnow captures, although extremely limited, also suggest the synchronous emergence of fry from cobble beds.

RELATIONSHIP OF LARVAL FISH DRIFT STUDY TO THE SAN JUAN RIVER IMPLEMENTATION PROGRAM

Task 5.3 IDENTIFY, PROTECT, AND RESTORE THE ENDANGERED FISH SPECIES OF THE SAN JUAN RIVER BASIN AND MANAGE THE NATIVE FISH COMMUNITY

Task 5.3.2 *Determine the status and trends of resident fish species*

Drift information can be used as a surrogate to provide information on the status and track potential trends of the resident fish community. This sampling method provided detailed information on the earliest period of a single cohort (age-0 fish). The utility of this information lies in its being merged with information obtained from sampling methods which yield samples that do not contain an accurate representation of this cohort (i.e., seining). The combined datasets can, over years, illustrate trends in population demographics. During the drift-netting study, we observed considerable fluctuations in the abundance of age-0 channel catfish. These changes will be tracked in future years as this cohort becomes susceptible to other collecting techniques.

Task 5.3.3 *Determine the life history of endangered and other native fish species and relationships to all other resident fish species*

We were able to gleam important information regarding life-history aspects of Colorado pikeminnow. The collection of drifting larval pikeminnow at the Four Corners site provided definitive evidence of a spawning bar upstream of RM 128. It is presumed, based on radio-telemetry work, that the spawning bar is located in the reach of the river known as the Mixer. That many of the early life-history traits of the San Juan River larval (drifting) pikeminnow were the same as reported for this species in other portions of the Upper Colorado River Basin, implies that other aspects of its reproductive biology are the same (i.e., back-calculated spawning dates derived from length, drift duration, swim-up period, spawning habitat, site affinity etc.). Similar information were obtained for most resident species.

Task 5.3.5 *Characterize fish community response to different annual flow regimes*

Data gathered from this study demonstrated differences in the magnitude of drift of selected species under varying annual flow regimes. Study years with highest spring-summer discharge generally resulted in the collection of more native (speckled dace, flannelmouth sucker, bluehead sucker) than nonnative (red shiner and channel catfish) individuals. Conversely, during years with low spring-summer discharge, nonnative fishes achieved some of their greatest abundances in drift samples. The number of drifting Colorado pikeminnow collected was too small to make quantitative statements regarding reproduction as related to the magnitude and pattern of discharge.

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From 1995-1997, sampling in both Utah and New Mexico was conducted by the following individuals from the Division of Fishes, Museum of Southwestern Biology, at the University of New Mexico: W. Howard Brandenburg, Stephen R. Davenport, Jules T. Dendy, Keith B. Gido, Jennifer E. Grace, Katherine M. Hoff, Nancy M. Johnston, W. Scott Knapp, John P. Larson, John P. Sherrod, Alexandra M. Snyder, and Joshua R. Walters.

Christopher S. Altenbach and W. Howard Brandenburg assumed responsibility for processing samples and identifying all larval fishes. Darrel E. Snyder (Larval Fish Laboratory, Colorado State University) provided expert training assistance and verified the identifications of all larval roundtail chub and Colorado pikeminnow collected during the drift-netting study. Alexandra M. Snyder coordinated laboratory work, oversaw curatorial activities, and ensured the permanent archiving of both specimens and associated collection data sheet and field notes. John P. Larson was the primary curatorial assistant.

Jennifer Fowler-Propst (USFWS - N.M. Ecological Services Office) graciously provided a trailer for use during the summers of 1995-1999 at the Four Corners station. Thomas E. Chart and Melissa A. Trammel (UDWR) provided a trailer for our use in 1995 at the Mexican Hat sampling locality. Since then, housing at the Mexican Hat locality has been provided by Richard Neff of Valles Trading Post. In addition, Mr. Neff has granted access and allowed us to establish the Mexican Hat sampling site at a secured reach of the San Juan River, just downstream of the public launching ramp. His continued assistance and friendship over the tenure of this work is greatly appreciated and has made the logistics of the project markedly easier.

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LITERATURE CITED

Bestgen, K. R., R. T. Muth, and M. A. Trammell. 1998. Downstream transport of Colorado squawfish larvae in the Green River drainage: temporal and spatial variation in abundance and relationships with juvenile recruitment. Unpublished report to the Colorado River Recovery Implementation Program: Project Number 32. 63 pp.

Hamman, R. L. 1981. Spawning and culture of Colorado squawfish in raceways. *Progressive Fish Culturist* 43: 173-177.

Hamman, R. L. 1986. Induced spawning of hatchery-reared Colorado squawfish. *Progressive Fish Culturist* 48: 72-74.

Haynes, C. M., T. A. Lytle, E. J. Wick, and R. T. Muth. 1984. Larval Colorado squawfish (*Ptychocheilus lucius*) in the Upper Colorado River Basin, Colorado. *The Southwestern Naturalist* 29:21-33.

Holden, P. B., and E. J. Wick. 1982. Life history and prospects for recovery of Colorado squawfish. pp. 98-108. *In*: W. H. Miller, H. M. Tyus, and C. A. Carlson, (eds.) Fishes of the upper Colorado River system: Present and future, Bethesda, MD: Western Division, American Fisheries Society.

Johnson, J. E., and R. T. Hines. 1998. Effect of turbidity on vulnerability of razorback sucker larvae to predation by Colorado squawfish and green sunfish. Abstract from 45th Annual Meeting (9-11 April 1998) of Southwestern Association of Naturalists, Albuquerque, NM.

Johnston, T. A., M. N. Gaboury, R. A. Janusz, and L. R. Janusz. 1995. Larval fish drift in the Valley River, Manitoba: influence of abiotic and biotic factors, and relationships with future year-class strengths. *Canadian Journal of Fisheries and Aquatic Sciences* 52: 2423-2431.

Lanigan, S. H., and C. R. Berry, Jr. 1981. Distribution of fishes in the White River, Utah. *The Southwestern Naturalist* 26:389-393.

Maddux, H. R., and W. G. Kepner. 1988. Spawning of bluehead sucker in Kanab Creek, Arizona (Pisces: Catostomidae). *The Southwestern Naturalist* 33:364-365.

McKinney, T., W. R. Persons, and R. S. Rogers. 1999. Ecology of flannelmouth sucker in the Lee's Ferry tailwater, Colorado River, Arizona. *Great Basin Naturalist* 59:259-265.

Meyer, C. W., and M. A. Moretti. 1988. Fisheries survey of the San Juan River, Utah, 1987. Final Report for Utah Division of Wildlife Resource-U.S. Bureau of Reclamation Cooperative Agreement 7FC-40-05050. Salt Lake City, UT.

Miller, W. J. 1995. San Juan River Colorado squawfish habitat suitability curves. W. J. Miller and Associates, Inc. Fort Collins, CO.

Minckley, C. O., and S. W. Carothers. 1979. Recent collections of the Colorado squawfish and razorback sucker from the San Juan and Colorado rivers in New Mexico and Arizona. *The Southwestern Naturalist* 24:686-687.

Minckley, W. L., and J. E. Deacon. 1968. Southwestern fishes and the enigma of "endangered species". *Science* 159:1424-1433.

Minckley, W. L. 1973. Fishes of Arizona. Phoenix: Arizona Game and Fish Department.

Moyle, P. B. 1976. Inland fishes of California. Berkeley: University of California Press.

Nesler, T. P., R. T. Muth, and A. F. Wasowicz. 1988. Evidence for baseline flow spikes as spawning cues for Colorado squawfish in the Yampa River, Colorado. *American Fisheries Society Symposium* 5: 68-79.

Platania, S. P., and K. R. Bestgen. 1988. Survey of the fishes of the lower San Juan River, New Mexico, Final Report for U.S. Bureau of Reclamation Contract 516.6-74-23. New Mexico Game and Fish Department, Santa Fe, NM.

Platania, S. P., K. R. Bestgen, M. A. Moretti, D. L. Propst, and J. E. Brooks. 1990. Status of Colorado squawfish and razorback sucker in the San Juan River, Colorado, New Mexico, and Utah. *The Southwestern Naturalist* 36:147-150.

Robinson, A. T., R. W. Clarkson, and R. E. Forrest. 1998. Dispersal of larval fishes in a regulated river tributary. *Transactions of the American Fisheries Society* 127:772-786.

Ryden, D. W., and L. A. Ahlm. 1996. Observations on the distribution and movements of Colorado squawfish, *Ptychocheilus lucius*, in the San Juan River, New Mexico, Colorado, and Utah. *The Southwestern Naturalist* 41:161-168.

Snyder, D. E. 1981. Contributions to a guide to the cypriniform fish larvae of the Upper Colorado River system in Colorado. U.S. Bureau of Land Management, Biological Sciences Series 3, Denver, CO. 81 pp.

Tranter, D. J., and P. E. Smith. 1968. Filtration performance. pp. 27-56. *In*: D. J. Tranter (ed.) Zooplankton sampling. UNESCO Press, Paris, France.

Tyus, H. M. 1985. Homing behavior noted for Colorado squawfish. *Copeia* 1985:213-215.

Tyus, H. M. 1986. Life strategies in the evolution of the Colorado squawfish (*Ptychocheilus lucius*). *Great Basin Naturalist* 46:656-661.

Tyus, H. M. 1990. Potamodromy and reproduction of Colorado squawfish in the Green River basin, Colorado and Utah. *Transactions of the American Fisheries Society* 119:1035-1047.

Tyus, H. M. 1991. Ecology and management of Colorado squawfish. pp. 379-402. *In*: W. L. Minckley and J. E. Deacon, (eds.) Battle Against Extinction: Native Fish Management in the American Southwest, University of Arizona Press, Tucson, AZ.

Tyus, H. M., and G. B. Haines. 1991. Distribution, habitat use, and growth of young Colorado squawfish in the Green River basin, Colorado and Utah. *Transactions of the American Fisheries Society* 120:79-89.

Tyus, H. M., and C. A. Karp. 1990. Spawning and movements of razorback sucker, *Xyrauchen texanus*, in the Green River basin of Colorado and Utah. *The Southwestern Naturalist* 35:427-433.

Tyus, H. M., R. L. Jones, and L. A. Trinca. 1987. Green River rare and endangered fish studies, 1982-1985. Final Report for Colorado River Fishes Monitoring Program, U.S. Bureau of Reclamation. U.S. Fish and Wildlife Service, Vernal, UT.

U.S. Department of the Interior. 1974. Taking, possession, transportation, sale, purchase, barter, exportation, and importation of wildlife. Federal Register 39[3] Part III:1158-1185.

Vanicek, C. D., and R. H. Kramer. 1969. Life history of the Colorado squawfish, *Ptychocheilus lucius*, and the Colorado chub, *Gila robusta*, in the Green River in Dinosaur National Monument, 1964-1966. *Transactions of the American Fisheries Society* 98:193-208.

Weiss, S. J., E. O. Otis, and O. E. Maughan. 1998. Spawning ecology of flannelmouth sucker, *Catostomus latipinnis* (Catostomidae), in two small tributaries of the lower Colorado River. *Environmental Biology of Fishes* 52:419-433.